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MANUFACTURING TECHNOLOGY FOR HIGH VOLTAGE POWER SUPPLIES (HVPS)

Volume II - Program Details

Northrop Grumman Corporation
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This technical report has been reviewed and is approved for publication.

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13. ABSTRACT
This report is the culmination of a multi-year manufacturing technology program sponsored by the Electronics Division of Wright Laboratory Manufacturing Technology Directorate (WL/MTM). The program was jointly conducted by Northrop Grumman Electronics and Integration Division as the prime contractor and Hughes Aircraft Company Technology Support Division as the principal subcontractor. The thrust of this program was to improve the reliability of High Voltage Power Supplies (HVPS). This was accomplished by conducting a comprehensive evaluation of the materials, components and processes used to produce HVPS. To demonstrate the benefits of the program the lessons learned were incorporated into two existing HVPS, ALQ-135 and AMRAAM. Several of these upgraded high voltage assemblies were fabricated and tested to measure the benefits resulting from the changes.
The report is published in four volumes. The first volume is a summary of the technical activity and highlights of the program. The remaining three volumes provide the specific program and procedural details and reference information generated in performance of the effort. This report, Volume II - Program Details, gives introductory and background information, the approach used, design/development considerations and general information for use by High Voltage Power Supply designers and manufacturers.

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DESIGN AND MANUFACTURING GUIDELINES FOR HIGH VOLTAGE POWER SUPPLIES

VOLUME 2

PROGRAM DETAILS

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GENERAL INTRODUCTION

The Guidelines contained here-in are presented in four volumes:

Volume 1, Design and Manufacturing Guidelines for High Voltage Power Supply, Program Summary.

Volume 2, Program Details, gives introductory and background information, the approach used, design/development considerations and general information for use by High Voltage Power Supply designers and manufacturers.

Volume 3, Procedural Details, contains procedures on how to perform the various component, material and process evaluations, and gives results obtained from the Northrop Grumman/ Hughes Aircraft Company efforts. The volume 3 procedures are basically stand alone documents and have been numbered as such. They can be referenced for specific areas of interest or treatment of problems; however, when reference is made to Model Test Structures, Volume 3 should be viewed for specific construction details.

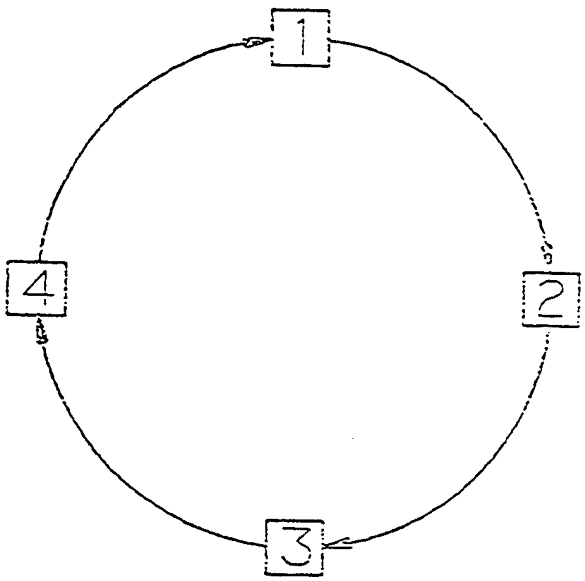
Volume 4, Reference Information, contains specific construction details on Model Test Structures used throughout the program as well as test results obtained from the various material and component studies.

The information developed in these four volumes is the result of a joint Northrop Grumman Electronics Systems and Hughes Electro-Optical Systems effort initially begun in mid-1990. The initiative and primary funding for this effort was provided by Wright-Patterson AFB, Wright Labs ManTech Directorate, project manager M. Price. Supplemental funding from internal R & D funds was also provided by Northrop Grumman. General Research Corporation (J. Basine, K. Dunker) and consultant, W. Dunbar, served as contract monitors during the course of the program.

Note: Because the information presented is from research provided by multiple sources within each of the two contractors (as well as numerous third party sources), the writing styles, formatting and print emphasis vary somewhat. This should not detract from the content in any way.

1.0 DESIGN CONSIDERATIONS

A successful HVPS requires a systematic design approach that takes into account the details and interactions of parts and processes needed to obtain reliable performance. Existing designs that need upgrades to improve either performance or reliability must also be viewed globally to obtain solutions that truly enhance performance rather than correcting a problem in one area while creating a problem in another. A four step systematic approach has evolved from the work on this program that has proven beneficial to accomplish the goals of a successful improvement program:



1. DEFINE GOALS AND OBJECTIVES
2. MODEL TEST STRUCTURES
3. STATISTICAL EVALUATION OF RESULTS
4. DECISION MAKING PROCESS

1.1 Quality Function Deployment

QFD is a systematic approach to product design that seeks to identify all the factors and variables that have a bearing on performance, and then systematically optimizes the components, materials and processes at the lowest levels via a matrix test program. Evaluation at the subassembly level then follows and is often via a model test structure (simulates actual hardware) to reduce time and cost while allowing a focused approach for the evaluation. Appendix 2-1 is the QFD for High Voltage Power Supplies.

1.2 Design Of Experiments

Analysis of process variations, comparative evaluation of encapsulant properties, or measurement of model test structure performance all require an understanding of how to design an experiment and create the statistical analysis associated with obtaining meaningful results.

The following sections describe a Taguchi statistical approach to designing a model test structure evaluation (section 1.2.1), analysis of variation (ANOVA) which allows a comparison of several groups of data (section 1.2.2), and a statistical plan for characterizing material and components (section 1.2.3).

1.2.1 Model Test Structures

Model test structures (MTSs) are physical devices that replicate a portion of the system of interest, and incorporate one or more of its key variables. MTSs should be as simple as possible - subject to the need to develop the information of interest. They can be as simple as a pair of electrodes encapsulated in a potting material.

In that example, when several sets of such electrodes are separated by one or more precisely known gaps, and are encapasulated in several different potting materials, the critical electric field behavior of the encapsulants can be studied as a function of applied voltage, voltage stress, ambient temperature, ambient humidity, encapsulant material type, encapsulation conditions and processes, etc. As can be seen from this example, a great deal of information can often be developed from very simple and inexpensive structures. And one of the principal virtues of simple structures is their low cost. Such MTS can often be tested in relatively large numbers for relatively low cost. In this way, multiple sets of experimental conditions can be tried, and a sufficient number of repetitions for each data point can be made in order to improve the data's statistical significance.

MTSs are used to test key independent variables that will affect some aspect of the power supply's performance. Some independent variables are nearly always critical to power supply performance. Among these are temperature, voltage stress, the mechanical and electrical properties of encapsulant materials, and particular characteristics associated with individual components in the power supply. Others may be specific to particular designs, or in-use requirements. In either case, identifying the key variables that will affect the performance of the power supply, or a portion of it, is the first step in designing an MTS. If it is likely that several variables will interact, as do temperature and the dielectric standoff properties of polymeric encapsulants for example, it may be important to incorporate both variables within a model test structure, in order to test and understand their interactions. Taguchi matrix-style design of experiments (DOE) studies are an ideal way to quickly develop an understanding of interactions among independent variables as they affect a particular dependent variable of interest.

When necessary, model test structures can be as complex as an entire subsystem. And, toward the end of any power supply design program, a prototype design will be produced in the form of an engineering development model (EDM) in order to test and verify the design concepts that were developed during earlier model test structure - design of experiments (MTS-DOE) studies, and to resolve an remaining issues identified in the QFDs. This EDM should represent the last MTS in a successful power supply design program.

MTSs are developed for testing, and they are best tested using a design of experiments approach. In a designed experiment, a plan is made to efficiently test for

the values of one or more dependent variables when the values of one or more independent variables are changed. Contrary to one's intuition, it is possible to vary more than one independent variable at a time, and get results that can be understood. The effects of a change in a specific independent variable on a specific dependent variable can be accurately determined even if all other variables are not held constant. And, as discussed above, by varying several independent variables in a single test, it is possible to understand variable - variable interactions. Nevertheless, it is not always either necessary or desireable to vary more than one variable. Conventional, non-matrixed experiments can also be designed experiments, and can sometimes facilitate understanding as well as, or better than, a more complex matrixed, multi-variate test.

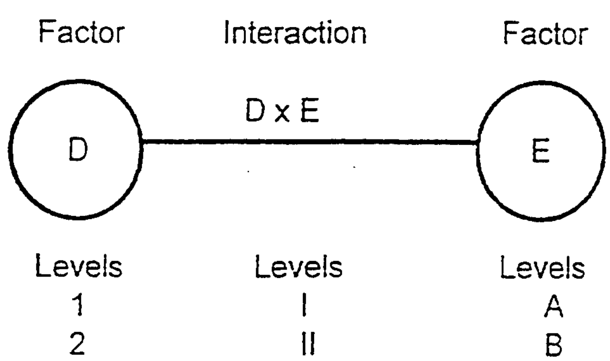
Multi-variate testing can, however, often help to minimize the total number of experiments that must be performed in order to garner the same information and understanding. Consider, for example, a simple three dimensional space defined by two independent variables and one dependent variable. In real systems, the response of the dependent variable to changes in the independent variables will generally be described by a regular surface, and this surface will often be a smoothly varying one. The properties of such a smoothly varying three dimensional surface can often be well enough understood by determining the values of the independent variable for only a very few key combinations of values for the dependent variables. These represent only a few points on the surface, perhaps at the corners at at a few points on the interior of the surface. Not only can the surface be understood, but its projections in each of the planes defined by a simgle independent variable and the dependent variable can also often be understood. It is in this same sense that matrixed, multi-variate DOEs can provide the necessary information with a relatively small number of data points, and can provide information on single variable effects even while more than one variable is being changed at a time.

For illustration, consider a designed experiment on series connected rectifier diodes, and this experiment can serve to illustrate the important considerations in DOE. In this experiment, we want to determine the operating voltage, V_{op}, of the diodes as a function of the key independent variables, the number of series connected diodes, the type of encapsulant used, and the temperature of the environment in which the diodes were operating. In the language of DOE, particularly when employing Taguchi matrices, these independent variables are referred to as "factors." The values for these variables are referred to as "levels." This term suggests discrete values for these variables, and that is how they are used. Each such discrete value for a factor is referred to as a level. In the case of our diode experiment:

Factor Name	Factor Symbol	Level 1	Level 2
Number of diodes in series	D	1	4
Type of encapsulant	E	A	B
Operating Temperature	T	Low	High

Thus, we could study single diodes and strings of four diodes, two different encapsulant materials, and two different operating temperatures, low (ambient), and high (elevated). The first two variables are inherently discretely valued - that it, it is only possible to have integral numbers for these variables. By choosing two levels for each, we have somewhat arbitrarily selected two of the many possible values for these variables. However, if these values make sense from a system standpoint, they can easily be justified. The third variable, temperature, is actually continuously valued - there are actually an infinite number of values for the variable the maximum and minimum temperature limits imposed by experimental conditions. The choice of two levels for this variable may appear to be equally arbitrary, however, if they make sense from an system viewpoint, their choice can be supported. The choices of factor sets and levels for each factor should be done by the HVPS component, material, design, packaging, process, test, and manufacturing engineers who are members of the multi-functional concurrent engineering design team.

Interactions can exist among these variables, and the interactions can also be assigned discrete levels, even if the interaction vaiable is continuously valued. For example:



The "D X E" notation indicates the interaction, resulting in different values for the dependent variable V_{op}, between the factors D and E. In this case, there are three factors, each of which has two levels. In addition, there are four interactions D x E, D x T, E x T, and D x E x T, each of which we can consider to be present at two levels, as discussed above.

The existence of three factors, each of which has two levels, defines an L_8 orthogonal array. This is one of the standard set of orthogonal arrays that have been published by Taguchi and others. Its appearance, in the form that includes all of the interactions, is shown below.

Run	D	E	D x E	T	D x T	E x T	DxExT
1	1	A	I	LOW	I	I	I
2	1	A	I	HIGH	II	II	II
3	1	B	II	HIGH	II	I	I
4	1	B	II	HIGH	II	I	I
5	4	A	II	LOW	II	I	II
6	4	A	II	HIGH	I	II	I
7	4	B	I	LOW	II	II	I
8	4	B	I	HIGH	I	I	II

This array, developed using linear algebra, defines a set of eight experimental runs, in terms of the the combinations of levels for each factor, that will exhaustively test the response of the dependent variable to the independent variables. In each run, the factors D, E, and T are set for the indicated levels. The interactions D x E, D x T, E x T, and D x E x T, will have the indicated levels in each run.

To perform the experiment, a set of MTSs are constructed that incorporate these factors, and the above sets of their levels. Like all other sets of MTSs, these incorporate four key properties:

- They are experimental samples that incorporate the factors and levels to be studied,
- All the MTSs in the matrixed set incorporate the same set of factors,
- MTSs from different runs in a matrixed set incorporate different combinations of levels, and
- Multiple identical samples (repeats) may be used in single experimental "runs" to improve the statistical significance of the result.

In the case where three "repeats" were used for each sample run, there will be three values for V_{op}, for each run, or a total of 24 results for the test. An abstract from the table of results might look
like that below:

Run	Level for "E"	Measured V_{op}	Totals
1	A	Va, Vb, Vc	1
2	A	Va, Vc, Vf	2
3	B	Vg, Vl, Vi	3
4	B	Vj, Vl, Vq	4
5	A	Vm, Vn, Vo	5
6	A	Vr, Ve, Vr	6
7	B	Vs, Ve, Vu	7
8	B	Vv, Vw, Vx	8

Here, for illustration, we have included the levels for one of the variables, "E", together with the run numbers, the measured values for V_{op}, and the totals for each run where, for example, $\Sigma 1 = Va + Vb + Vc$.

Several types of averages are defined frome these data. The "Grand Average", "GA" is defined as:

$$GA = \frac{\Sigma 1 + \Sigma 2 + \ldots + \Sigma 8}{3 \times 8}$$

while the "Level Means", E_A and E_B, are defined as:

$$E_A = \frac{\Sigma 1 + \Sigma 2 + \Sigma 5 + \Sigma 6}{3 \times 4} \qquad E_B = \frac{\Sigma 3 + \Sigma 4 + \Sigma 7 + \Sigma 8}{3 \times 4}$$

Similar level averages would be calculated for diodes, D_1 and D_4, and for temperatures T_{LOW} T_{HIGH}, in a similar way. Also, similar level averages would be calculated for the interactions D x E, D x T, E x T, and D x E x T. These averages are used to determine the effects of factor level and interactions on V_{op}.

To determine the total effect of a particular factor on V_{op}, subtract the least level mean from the greatest. For example, if the level mean for D_1 is greater than that for D_4, then the total effect for variable D is:

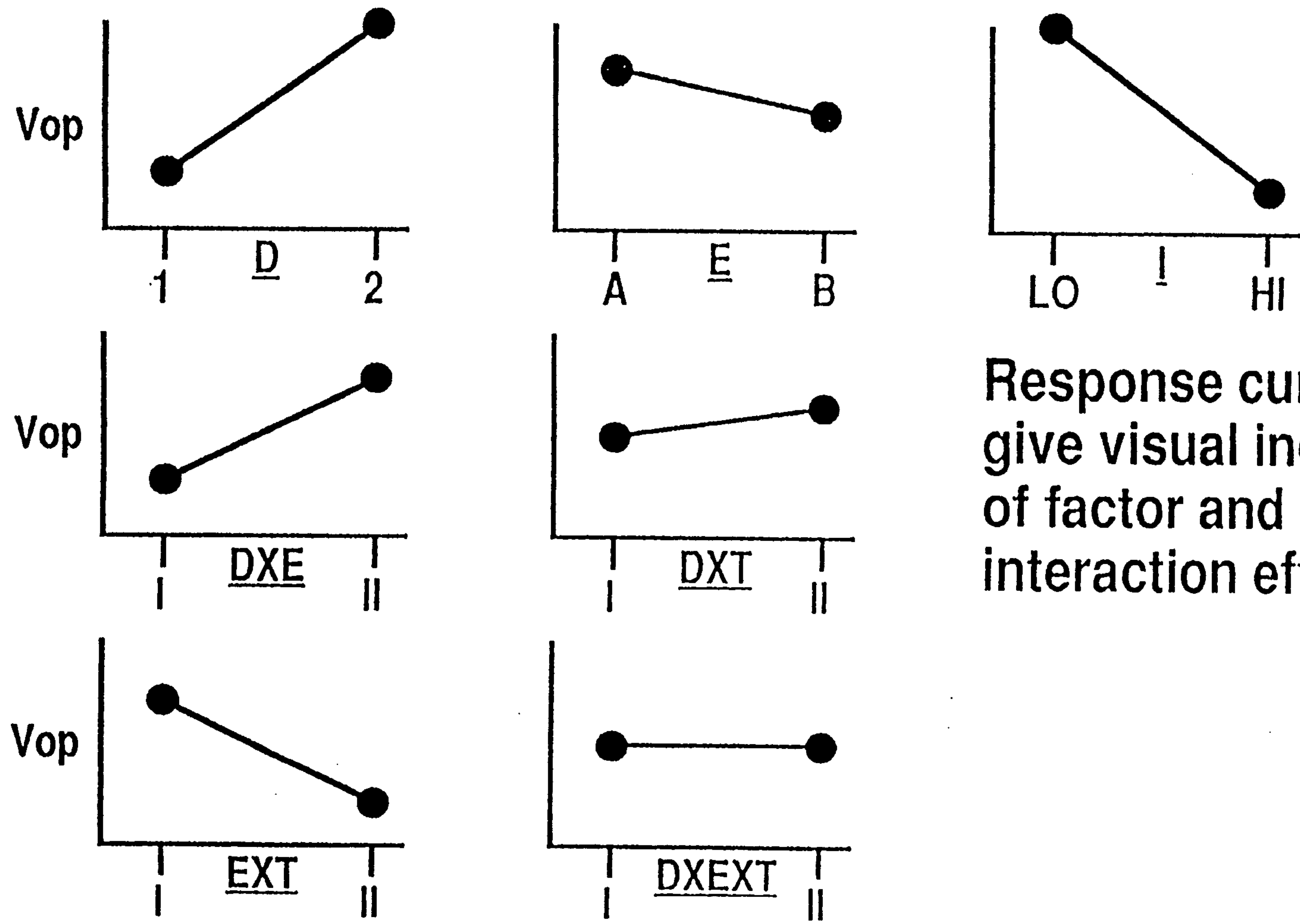
$$\text{Effect } D = D_1 - D_4, \text{ or}$$
$$\text{Effect } D = (D_1 - GA) - (D_4 - GA)$$

if the level means are normalized to the Grand Average. Since the interactions are treated as if they were factors, the total effect of interaction D x E is:

$$\text{Effect } D \times E = D \times E_I - D \times E_{II}$$

assuming that D x E_I is greater than D x E_{II}. Of all of the factors and interactions calculated, the one with the largest total effect is the most important one, called the "control factor." Usually, the importance of the various factors and interactions can best be determined by graphing. An example of this is shown in on the following page.

Graphing Results – Response Curves



Response curves give visual indication of factor and interaction effects

In the cases where these response curves have the largest slopes, the effects of the factors on the dependent variable are the largest. In the case they are relatively flat the factor does not affect the dependent variable as much. Also, the sign of the slope is important, as shown in the graphs.

In the case where an optimized value of the dependent variable is desired, often a maximumized or minimized value for this variable, it is possible to predict the combination of factor levels that will produce this optimized result. As shown in the graphs, level 2 for factor D, level A for factor E, and level II for factor D X E each individually produce the largest values of V_{op}. If the highest value for V_{op} is considered optimum, these levels could be expected to produce the optimum level of V_{op}. That optimum level, with respect to these two factors and this one interaction, could be calculated as follows:

$$\text{Optimum } V_{op} = GA\ (D_4\text{-}GA) \div (E_A\text{-}GA) + (D \times E_{II} - GA)$$

The full calculation would include all of the factors and interactions in an obvious way. The last step in the matrixed DOE process would be to perform an experimental run using the optimized values for the factor levels, and compare the measured value for the dependent variable with the predicted value.

ANOVA, or analysis of variance, is a mathematical procedure used to allocate the amount of variation resulting from each factor as well as the proportion of the total variation contributed by each factor. It is a useful method when sample to sample variation is observed in DOE studies with large numbers of samples. ANOVA techniques can help pinpoint those factors that are sources of variation in the results obtained from MTS-DOE studies, and which could be sources of variation in the final, manufactured product. Some definitions associated with ANOVA analyses are presented on the following pages as well as an example of ANOVA application to determine control limits for material properties. This latter document by Dr. Ajit Tamhane of Northwestern University is an analysis of several batches of silicone material tested at an outside laboratory and compared to the specification limits proposed by Emerson & Cuming, the material producer. Finally, a statistical test plan for characterizing a key material or component element is presented as an example of the type of evaluation that might be necessary to fully evaluate that elements' performance.

1.2.2 Analysis Of Variance (ANOVA)

ANOVA: is a method for comparing several groups of data to determine if a treatment is significant in relation to the residual error within the group. Anova uses the sum of squares and mean squares to determine significance.

Total sum of squares(SS) = error SS + treatment SS or:

$$\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij}-\overline{x})^2=\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij}-\overline{x_i})^2+\sum_{i=1}^{k}n_i(\overline{x_i}-\overline{x})^2$$

where x_{ij} = *the individual records of the group*

$\overline{x}$ = *the grand average of the group*

$\overline{x_i}$ = *the average of the* i^{th} *subgroup*

n_i = *the number of records within the* i^{th} *subgroup*

Error, also called "within" sample variation, is a measure of the imprecision of testing, individual piece variation, etc. regardless of treatment. Treatment, or "between" variation, is the measure of the effect of a specific method or process being investigated.

Group: a collection of data records, (x_{ij}), meeting defined criteria such as all the samples analyzed on 1-10-90 regardless of test site.

Subgroup: a set of records,(x_i), obtained under identical conditions i.e. the same date, test site, conditioning parameters, etc.

Between DF(degrees of freedom): 1 less than the number of groups, (k).

Within DF(degrees of freedom): the number of records within a group,($N=\Sigma n_i$), - the number of groups(i).

Total DF: the number of records within a group,(N), - 1

Between SS(Sum of Squares): the difference squared between the subgroup average and the grand or group average.

Within SS(Sum of Squares): the difference squared between the individual data records and the group average.

Between MS(Mean Square): the between SS ÷ the between degrees of freedom, (k-1). This estimates σ^2, the true variance of the treatment effects.

$$\frac{\left(\sum_{i=1}^{k} n_i (\overline{x_i} - \overline{x})^2\right)}{k - 1}$$

Within MS(Mean Square): the within SS ÷ the within degrees of freedom, (N - k). This estimates the variation due to chance.

$$\left(\frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij} - \overline{x_i})^2}{N - k}\right)$$

F: Between MS ÷ Within MS. If each the within and between degrees of freedom are at least 2, an F value greater than 20 is significant to 95 % confidence. As the degrees of freedom increase, the F value becomes significant at lower levels.

ANALYSIS OF VARIANCE OF DATA ON PROPERTIES OF RED RUBBER AND ITS APPLICATION TO CALCULATE CONTROL LIMITS

(Test Site = Broutman, Batches = 30, 33, 47, 77, 99)

by Dr. Ajit C. Tamhane

A) ANALYSIS OF VARIANCE

The basic model underlying the analysis of variance (ANOVA) is as follows in this case. For a given property X (X = Compressive Modulus, Tear Strength and Tensile Strength), let X_{ij} be the jth reading for the ith batch, $i = 30, 33, 47, 77, 99; j = 1, 2, \ldots, n_i$ where n_i is the sample size used for the ith batch. Then

$$X_{ij} = \text{Batch Mean } \mu_i + \text{ Measurement Error } e_{ij}$$

and

$$\text{Variance}(X_{ij}) = \text{Variance}(\mu_i) + \text{Variance}(e_{ij}).$$

The above equation is symbolically expressed as

$$\sigma^2_{\text{total}} = \sigma^2_{\text{batch}} + \sigma^2_{\text{error}}.$$

The ANOVA enables us to obtain estimates of σ^2_{batch} and σ^2_{error} using the formulas

$$\sigma^2_{\text{error}} = \text{MS}_{\text{error}}$$

and

$$\sigma^2_{\text{batch}} = (\text{MS}_{\text{batch}} - \text{MS}_{\text{error}})/n$$

where n is the (average) sample size per batch (assuming that the n's for different batches are not too different). The ANOVA also gives an F- statistic,

$$F = \frac{\text{MS}_{\text{batch}}}{\text{MS}_{\text{error}}}$$

which can be used to test whether there is a significant between batch (batch-to-batch) variation.

Before performing the ANOVA, any outliers were removed using the ASTM Standard Practice for Dealing with Outlier Observations (E 178-80). The final results are summarized below.

1) Compressive Modulus:

The summary statistics for batches are as follows.

Batch	n	Min	Max	Mean	Std. Dev.
30	24	794.10	855.70	818.53	17.06
33	24	866.04	1615.44	1176.58	190.71
47	24	772.00	945.23	866.70	43.03
77	23	925.00	1094.00	1003.22	46.18
99	23	774.00	967.00	891.09	44.39
Total	118	772.00	1615.44	951.29	92.32

We see that Batch 33 has unusually high mean and high standard deviation. Therefore this batch was dropped from further calculations.

The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Batches	429144.51	3	14048.17	92.26	.0001
Error	139538.91	90	1550.43		
Total	568683.42	93			

From this we obtain the following estimates. (Avg. $n = 23.6$.)

$$\sigma^2_{\text{error}} = 1550.43, \sigma^2_{\text{batch}} = 6021.18.$$

2) Tear Strength:

The summary statistics for batches are as follows.

Batch	n	Min	Max	Mean	Std. Dev.
30	24	24.20	29.50	26.75	1.27
33	28	26.20	30.60	28.18	1.16
47	28	26.60	32.10	29.29	1.28
77	24	30.90	36.50	33.05	1.42
99	20	25.10	30.60	27.72	1.27
Total	124	24.20	36.50	29.02	1.28

The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Batches	569.67	4	142.42	87.08	.0001
Error	194.63	119	1.64		
Total	764.29	123			

From this we obtain the following estimates. (Avg. $n = 24.8$.)

$$\sigma^2_{\text{error}} = 1.64, \sigma^2_{\text{batch}} = 5.68.$$

3) Tensile Strength:

The summary statistics for batches are as follows.

Batch	n	Min	Max	Mean	Std. Dev.
30	19	552.38	690.37	632.06	33.87
33	17	576.00	641.60	612.56	16.53
47	19	571.90	670.50	628.94	28.36
77	22	569.60	633.30	602.09	18.06
99	20	537.10	613.60	586.75	21.10
Total	97	537.10	690.37	611.89	24.41

The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Batches	28019.06	4	7004.77	11.76	.0001
Error	54800.03	92	595.65		
Total	82819.09	96			

From this we obtain the following estimates. (Avg. $n = 19.4$.)

$$\sigma^2_{\text{error}} = 595.65, \sigma^2_{\text{batch}} = 330.37.$$

B) CALCULATION OF CONTROL LIMITS

The control limits will be based on the mean computed from $n = 10$ measurements for each property. For a given property X, denote this mean by $\bar{X}$. Then it is well-known that

$$\text{Variance}(\bar{X}) = \sigma^2 = \sigma^2_{\text{batch}} + \sigma^2_{\text{error}}/n.$$

The control limits are then given by

$$\overline{\overline{X}} \pm 3\sigma,$$

where $\overline{\overline{X}}$ denotes the overall average of past batches that were in statistical control. The calculation of these control limits for the three properties is shown in the following table.

Property	$\overline{\overline{X}}$	σ_{batch}	σ_{error}	σ	Control Limits
Compressive Modulus	893.77	77.60	39.38	78.59	[658.00, 1129.54]
Tear Strength	29.02	2.38	1.28	2.42	[21.77, 36.27]
Tensile Strength	611.89	18.18	24.41	19.75	[552.65, 671.13]

C) TOLERANCE LIMITS PROPOSED BY E & C

Mr. Kevin Yee of E & C has proposed to use 95-99 tolerance limits (95% probability that the means (based on 10 measurements) of the 99% of all future batches will fall within these limits) as the specification limits for tensile strength and tear strength. The following points should be noted regarding this proposal.

- We should not lose sight of the fact that the specification limits must come from engineering or design considerations. At present we do not have such a basis available for deciding the specification limits, hence the resort to using the control limits or the tolerance limits in their place. The latter do not guarantee that the part will function properly. The only thing they check is whether the variation from the past average is within statistical limits.

- The tolerance limits are generally far too wide to be useful in application if based on so few batches. They permit excessive variation.

- The E & C calculations do not separate the contributions to the total variation from between batches and within batches (which is essentially variation due to measurement errors, assuming each batch is quite homogeneous). The standard deviation S that they calculate estimates $\sigma = \sqrt{\sigma^2_{\text{batch}} + \sigma^2_{\text{error}}/n}$, but not its components. Also it is based on too few batches, and hence not a very reliable estimate. The separate components give useful information.

D) GAGE STUDY

The gage study data provided by Broutman was analyzed using ANOVA techniques. There are two factors: 1) Operator, and 2) Sheet. Both factors are regarded as random. The location on the sheet is a possible factor, but not sufficient data are available to study the effects of location. Therefore the following model was considered:

$$X_{ijk} = \mu + \alpha_i + \beta_j + e_{ijk}$$

where X_{ijk} is the kth measurement on the jth sheet by the ith operator ($i = 1,2,3, j = 1,2,3,4, k = 1,2,\ldots,n_{ij}$), μ is the overall mean, α_i is the "effect" of the ith operator ($i = 1,2,3$), β_j is the "effect" of the jth sheet ($j = 1,2,3,4$) and e_{ijk} is the measurement error corresponding to this measurement. The total variance can be partitioned as

$$\text{Variance}(X_{ijk}) = \sigma^2_{\text{total}} = \sigma^2_{\text{operator}} + \sigma^2_{\text{sheet}} + \sigma^2_{\text{error}}.$$

The results are as follows.

1) Elongation: The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Operator	468.19	2	234.09	4.05	.0231
Sheet	35.91	3	11.97	0.21	.8912
Error	3124.45	54	57.86		
Total	3628.54	59			

The conclusion here is that there are significant differences between the operators, but the sheets do not differ significantly. Operators 1 and 2 are quite close in their measurements (their means are 82.68 and 82.07, respectively), and also have about the same variation (their SD's are 6.70 and 5.56, respectively), but Operator 2 has higher mean = 88.28 and higher SD =9.51. The variance components are estimated to be

$$\sigma^2_{\text{error}} = 57.86, \sigma^2_{\text{operator}} = 8.82, \sigma^2_{\text{sheet}} = 0.$$

2) Tensile Strength: The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Operator	178.54	2	89.27	0.12	.8876
Sheet	978.41	3	326.14	0.44	.7279
Error	40357.73	54	747.37		
Total	41514.69	59			

The conclusion here is that there are no significant differences between either the operators or the sheets. The operator means are quite close (560.40, 557.78 and 561.96, respectively). Their SD's are 18.00, 36.45 and 22.87. Note that Operator 2 again has the highest variation. The variance components are estimated to be

$$\sigma^2_{\text{error}} = 747.37, \sigma^2_{\text{operator}} = 0, \sigma^2_{\text{sheet}} = 0.$$

3) Tensile Modulus:
The ANOVA table is as follows.

Analysis of Variance

Source	Sum of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	p-value
Operator	64932.58	2	32466.29	9.11	.0004
Sheet	12802.68	3	4267.56	1.20	.3913
Error	192376.74	54	3562.53		
Total	270112.01	59			

The conclusion here is that there are significant differences between the operators, but the sheets do not differ significantly. Operators 1 and 3 are relatively close in their measurements (their means are 726.75 and 752.12, respectively); Operator 1 has SD = 44.96 and Operator 3 has SD = 29.88. Operator 2 has much lower mean = 673.20 and the highest SD = 88.79. The variance components are estimated to be

$$\sigma^2_{\text{error}} = 3562.53, \sigma^2_{\text{operator}} = 1080.91, \sigma^2_{\text{sheet}} = 47.00$$

On the whole, sheets are fairly homogeneous (because they are made from the same batch), but the operators do differ from each other; the differences are mainly due to Operator 2, whose measurements differ from those of Operators 1 and 3, and who has the highest variation in each case.

1.2.3 Statistical Test Plan For Characterizing Materials And Components

Introduction

It is essential that any experimental results of this manufacturing technology program be reproducible and validatable by other HVPS manufacturers or interested organizations. Conclusions must be sound in accordance with proven statistical techniques.

With this as a goal, such things as sample size, success criteria, and desired level of confidence must be established prior to conducting the test programs. To attack the problem of determining such things as sample size when there is no existing reliable data, several assumptions must be made. Factors such as type of data distribution and repeatability of a test method (including the equipment and operator) must be estimated in order to develop a reasonable plan. Such things as accuracy of test results can be assured by verifying the results from a primary test site at a secondary test site. If there is significant disagreement between the two, a third or referee test site may be needed.

General Development

It is assumed that material and component properties or some transformation of them (i.e. log or inverse) are distributed normally. However lifetime data (MTBF) is assumed to be distributed exponentially. These initial assumptions will be verified and modified as necessary as the first test results are evaluated.

Material Plan

Sample Size

For the initial runs assume that the test method is repeatable within +/- 10% of the true mean (μ) value and that if the appropriate number of samples are tested, the average value (x-bar) will be within $\pm$ 2% of the true mean.

To determine the appropriate sample size, the following standard will be used:

$$n = \left(\frac{Z * \sigma}{a} \right)^2$$

(equation 1)

where

- n= number of samples
- z= critical value from the Standard Normal Distribution corresponding to the chosen confidence interval
- a= margin of error for μ
- σ= sigma, the true standard deviation for the population from which the samples are drawn

Since sigma is the standard deviation of an infinite population and therefore unknown, it must be estimated by using the fact that in a normal distribution; 68% of the population fall within $\pm 1\sigma$, 95% of the population fall into $\pm 2\sigma$, and 99.7% fall into the $\pm 3\sigma$ range.

Taking a conservative approach, $\underline{\sigma}$ is estimated as the total range of test values, $\underline{R}$, divided by 4. The range is divided by 4 rather than 6 since there is so little gain in probability between $\pm 2\sigma$ and $\pm 3\sigma$. Dividing by 6 then, might define an insufficient sample size. Especially for the initial attempts, it is better to err on the side of caution. Thus the equation becomes:

$$n = \left(\frac{R * Z}{4 * a} \right)^2$$

(equation 2)

Once the initial testing is complete it may become crucial to reevaluate any preliminary assumptions. If the sample range is greater than 20% of the sample average, it would be desirable to examine the test method, equipment, technique, etc., to determine if there are any attributable causes for the sample variation. If any cause of variance can be identified, it should be corrected and another set of samples run. If attributable cause cannot be found, then the initial assumption, that the range is within ± 10% of the mean, must be rejected. If any known attributable cause is not eliminated, then the set will not be random and cannot be used to approximate a normal distribution.

If the testing shows a lesser variation than assumed, the number of samples necessary can be reduced or a higher confidence level assigned.

Note that if the sample size n is prohibitively large, a different set of parameters may need to be established. For values of n at other conditions, see Tables 1 and 2.

Once the testing is complete for any given parameter, the sample average (x-bar) and sample standard deviation (S) will be calculated. These results are a measure of the precision of the test method and are denoted as "within" calculations.

Once the "within" sample variation has been determined, "between", or batch to batch limits can be set. Because of the slow rate of manufacture, the number of samples is predetermined. Every batch must be tested. For consistency, five batches will be tested as a compromise between precision and timeliness. Five sample batches will allow for a 90% confidence if the range is not more than 5.42 times greater than the margin of error. This can been seen from equation 2) when the appropriate substitutions are made.

$$5 = \left(\frac{R * 1.65}{4 * a} \right)^2 = \left(\frac{R}{a} * 0.4125 \right)^2$$

$$\frac{R}{a} = \frac{\sqrt{5}}{0.4125} = 5.42$$

Significance

In the "between" part of the consistency phase, "a" will be defined as the standard deviation of the "within" sample testing. Therefore any statements about consistency are accurate within the test method variation. X-bar and S will be calculated for each batch data set. The significance of any differences within certain confidence levels will be tested with pooled data calculations(t-test for mean and F-test for variance). The equation for the t-test is:

$$|t| = \frac{|\overline{X_1} - \overline{X_2}|}{\sqrt{\dfrac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{(n_1-1) + (n_2-1)}} * \sqrt{\dfrac{1}{n_1} + \dfrac{1}{n_2}}}$$

(equation 3)

The calculated t value would then be compared to a table t value, $t_{(v,\alpha)}$ where $V = (n_1-1) + (n_2-1)$, and $\alpha = 1 -$

TABLE 1 SAMPLE SIZE AT VARIOUS RANGE AND ERROR VALUES

$z =$ 1.65 (90% confidence)

Range as a percent of μ

a as % μ	\R a\	5%	10%	20%	25%	50%	100%
	1%	4.3	17.0	68.1	106.3	425.4	1701.6
	2%	1.1	4.3	17.0	26.6	106.3	425.4
	3%	0.5	1.9	7.6	11.8	47.3	189.1
	4%	0.3	1.1	4.3	6.6	26.6	106.3
	5%	0.2	0.7	2.7	4.3	17.0	68.1
	6%	0.1	0.5	1.9	3.0	11.8	47.3
	7%	0.1	0.3	1.4	2.2	8.7	34.7
	8%	0.1	0.3	1.1	1.7	6.6	26.6
	9%	0.1	0.2	0.8	1.3	5.3	21.0
	10%	0.0	0.2	0.7	1.1	4.3	17.0
	11%	0.0	0.1	0.6	0.9	3.5	14.1
	12%	0.0	0.1	0.5	0.7	3.0	11.8
	13%	0.0	0.1	0.4	0.6	2.5	10.1
	14%	0.0	0.1	0.3	0.5	2.2	8.7
	15%	0.0	0.1	0.3	0.5	1.9	7.6
	20%	0.0	0.0	0.2	0.3	1.1	4.3
	25%	0.0	0.0	0.1	0.2	0.7	2.7

TABLE 2 SAMPLE SIZE AT VARIOUS RANGE AND ERROR VALUES

z= 1.96 (95% confidence)

Range as a percent of u

	\R a\	5%	10%	20%	25%	50%	100%
a as % u	1%	6.0	24.0	96.0	150.1	600.3	2401.0
	2%	1.5	6.0	24.0	37.5	150.1	600.3
	3%	0.7	2.7	10.7	16.7	66.7	266.8
	4%	0.4	1.5	6.0	9.4	37.5	150.1
	5%	0.2	1.0	3.8	6.0	24.0	96.0
	6%	0.2	0.7	2.7	4.2	16.7	66.7
	7%	0.1	0.5	2.0	3.1	12.2	49.0
	8%	0.1	0.4	1.5	2.3	9.4	37.5
	9%	0.1	0.3	1.2	1.9	7.4	29.6
	10%	0.1	0.2	1.0	1.5	6.0	24.0
	11%	0.0	0.2	0.8	1.2	5.0	19.8
	12%	0.0	0.2	0.7	1.0	4.2	16.7
	13%	0.0	0.1	0.6	0.9	3.6	14.2
	14%	0.0	0.1	0.5	0.8	3.1	12.2
	15%	0.0	0.1	0.4	0.7	2.7	10.7
	20%	0.0	0.1	0.2	0.4	1.5	6.0
	25%	0.0	0.0	0.2	0.2	1.0	3.8

confidence. If $t_{calc} > t_{(\nu,\alpha)}$ then the samples are significantly different.

The t-test assumes that $\sigma_1 = \sigma_2$. To test this hypothesis, an F-test is used. The equation for this is:

$$F = \frac{S^2_1}{S^2_2} \quad if\ S^2_1 \geq S^2_2$$

$$F = \frac{S^2_2}{S^2_1} \quad if\ S^2_1 < S^2_2$$

Where S_1 and S_2 are the sample deviations, S^2_1 and S^2_2 are the sample variances, and σ is the population (or infinite) standard deviation. If $F \leq F(\nu_{numerator}, \nu_{denominator})$ at some α, then the hypothesis that $\sigma_1 = \sigma_2$ may be accepted at a level of significance α, and the above t-test is applicable.

Success Criteria

If the range of means(x-bars) for the "between" batch tests of any property is greater than 5.42*a the material will be determined to be inconsistent with respect to the parameter being tested. A material may be inconsistent in some properties but consistent in others.

At this point, the consistency data will be communicated to the vendor who may then choose to improve his process and product. If the vendor does choose to improve the consistency of his product, the product should be retested to reflect improved processing. If the vendor chooses not to reduce the variability, the data will stand as is.

Characterization

With test data available, the sample size for characterization testing will be recalculated using the "within" sample mean (x-bar) and standard deviation (S). the equation for this is similar to equation 2.

Since S is known, n can be recalculated for less variable

$$n = \left(\frac{z * S}{a}\right)^2$$

parameters since a smaller number of test samples will furnish the desired confidence. Under no condition will less than three samples be run. For each property determined, an average, a standard deviation and a confidence level will be calculated and published.

Component Test Plan

Component testing involves at least two types of distribution, normal for component properties and Weibull for component life testing. Note that a normal distribution assumes that once infant failures have occured, the performance is time dependant until wear-out occurs (the bath tub curve); whereas, a Weibull distribution is based on a mechanism which produces time dependant life. In the case of high voltage hardware for example, corona discharge could be that mechanism since the discharge produces cumulative damage to insulating systems. The treatments for each follow.

Life testing

One of the most significant attributes of any component or unit is its working life or Mean Time Between Failure (MTBF). Since this life data is usually not normal in distribution, the assumptions and equations used above are no longer applicable. Instead life data may be assumed to be a type of Weibull distribution. For the initial estimations the data is assumed to be exponential (a Weibull distribution having shape parameter β=1) to simplify some of the calculations.

Sample Size

To estimate the number of samples required for life testing, the equation is:

$$r = n * p$$

r = the number of failures
n = the number of samples run
p = the proportion of failure = $1 - e^{(-\lambda T)}$
T = the time of test termination
λ = $(\mathrm{MTBF})^{-1}$

Since none of this is known, it is essential to assume preliminary values. To achieve a reasonable confidence in the estimated MTBF, it is necessary to observe a high number of failures. To accomplish this, either a large number of samples must be tested or the failure proportion term must be made large by making T larger. If the test items are expensive and/or difficult to obtain, increasing T is the more practical method.

For example, if the expected MTBF is 2000 hours, and ten units are available for test:

$$r = n * \left(1 - e^{\frac{-T}{MTBF_{expected}}}\right)$$

$$\frac{r}{n} = 1 - e^{\frac{-T}{MTBF_{expected}}}$$

$$.7 - 1 = -e^{\frac{-T}{2000}} \quad (\text{ for } r=7 \text{ which is "large" })$$

$$e^{\frac{-T}{2000}} = 0.3$$

$$\frac{-T}{2000} = \ln(0.3)$$

$$T = 2408 \ hours$$

To get a reasonable chance of observing 7 failures, the test must run at least 2408 hours. More time will allow for greater confidence.

If time is not the limiting quantity, the sample size,n, may be estimated using equation 5. By deciding the test termination time,t_o, e.g., 3000 hours, and substituting, the equation becomes:

$$7 = n\left(1 - e^{-\frac{3000}{2000}}\right) or \ n = 9.0105$$

Since at least 7 observed failures are needed, the sample size is rounded up to 10.

MTBF and Confidence

After the test has been completed, then the estimated MTBF

($MTBF_{est}$) may be calculated from:

$$\frac{\sum_{i=1}^{r} t_i + (n - r)\, t_0}{r}$$

where t_i = the observed failure times

t_o = the time of test termination

To be sure that the true MTBF (μ) is captured by a confidence interval around the $MTBF_{(est)}$ with desired probability, a confidence level must be fixed and the limits calculated. For a time truncated test, the limits are:

$$\frac{2 * r}{\chi^2_{2r,\frac{\alpha}{2}}} * MTBF_{est} = lower\ limit$$

$$\frac{2 * r}{\chi^2_{2r,1-\frac{\alpha}{2}}} * MTBF_{est} = upper\ limit$$

If the desired confidence is 90%, then α = .10, the probability that MTBF will fall outside the confidence limits. The probability of being outside the confidence limits is equal on either the upper or lower end, or .05 for each. Using the previous example and substituting the values, the limits become:

$$\frac{2 * 7}{\chi^2_{14,.05}} * MTBF_{est} = \frac{14}{23.68} * MTBF_{est} = lowe$$

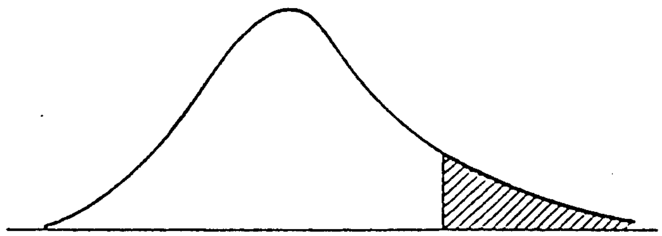
$$\frac{2 * 7}{\chi^2_{14,.95}} * MTBF_{est} = \frac{14}{6.571} * MTBF_{est} = uppe$$

For any experimental data, the confidence level and the confidence interval will be identified. Note: The values 23.68 and 6.572 in the above equations are from the Chi-Squared distribution table (see next page). For the number of failures, r=7, the Chi Squared values are located in the 2r line and under the .95 and .05 columns (which represent +/- .05 or a=.1).

Life Testing

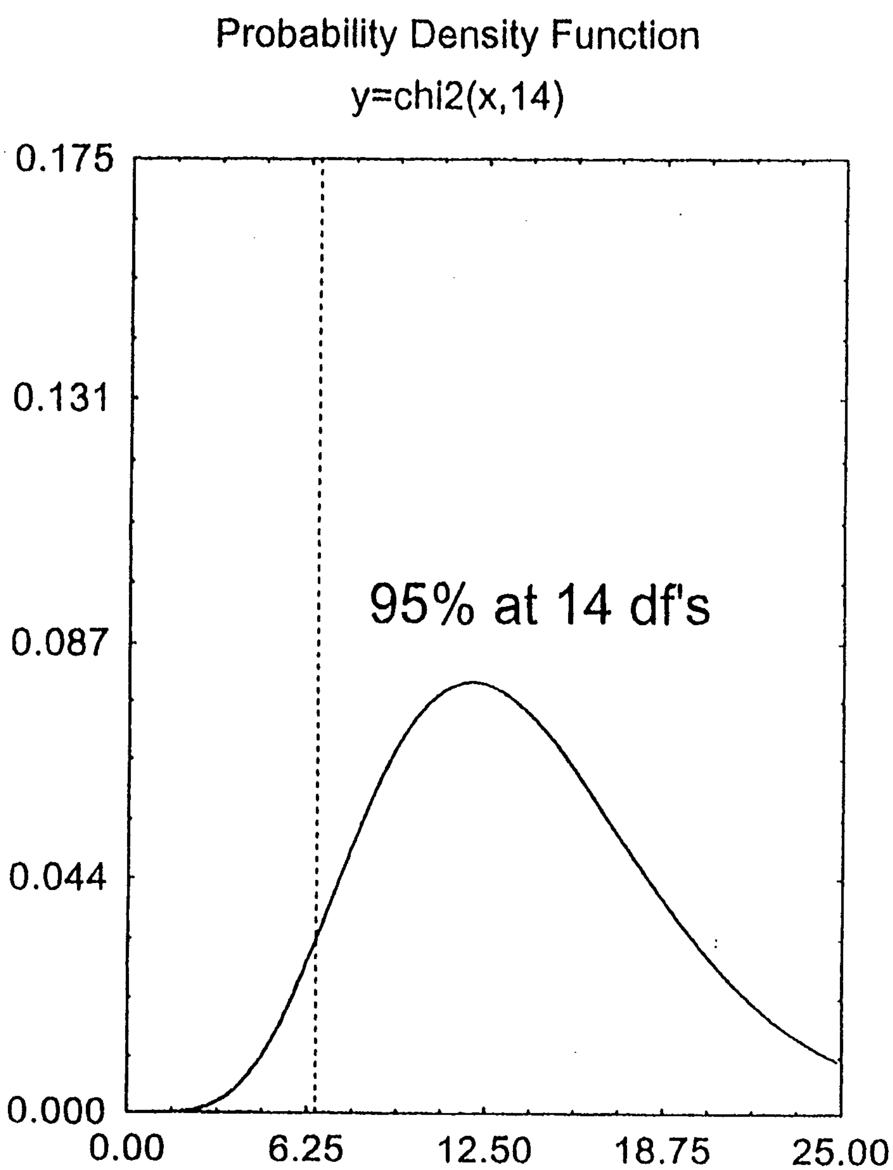
Life tests will be performed under a variety of stresses such as temperature and vibration. The results obtained will then be correlated, if possible, to actual lifetime. The sample size will be calculated as above with possible differences in assumed MTBF and confidence levels adopted.

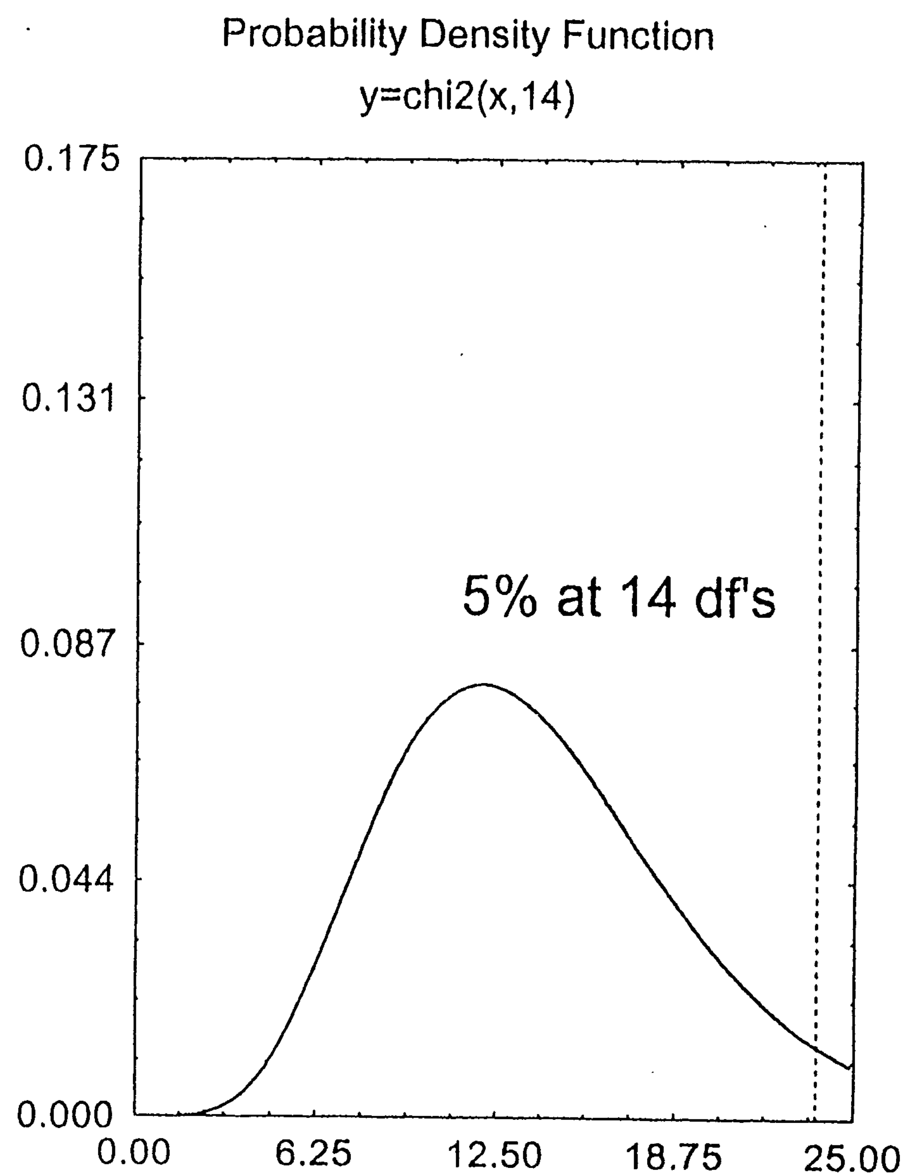
Appendix III Percentage Points of the χ^2 Distribution[a]



ν	α 0.995	0.990	0.975	0.950	0.500	0.050	0.025	0.010	0.005
1	0.00 +	0.00 +	0.00 +	0.00 +	0.45	3.84	5.02	6.63	7.88
2	0.01	0.02	0.05	0.10	1.39	5.99	7.38	9.21	10.60
3	0.07	0.11	0.22	0.35	2.37	7.81	9.35	11.34	12.84
4	0.21	0.30	0.48	0.71	3.36	9.49	11.14	13.28	14.86
5	0.41	0.55	0.83	1.15	4.35	11.07	12.38	15.09	16.75
6	0.68	0.87	1.24	1.64	5.35	12.59	14.45	16.81	18.55
7	0.99	1.24	1.69	2.17	6.35	14.07	16.01	18.48	20.28
8	1.34	1.65	2.18	2.73	7.34	15.51	17.53	20.09	21.96
9	1.73	2.09	2.70	3.33	8.34	16.92	19.02	21.67	23.59
10	2.16	2.56	3.25	3.94	9.34	18.31	20.48	23.21	25.19
11	2.60	3.05	3.82	4.57	10.34	19.68	21.92	24.72	26.76
12	3.07	3.57	4.40	5.23	11.34	21.03	23.34	26.22	28.30
13	3.57	4.11	5.01	5.89	12.34	22.36	24.74	27.69	29.82
14	4.07	4.66	5.63	6.57	13.34	23.68	26.12	29.14	31.32
15	4.60	5.23	6.27	7.26	14.34	25.00	27.49	30.58	32.80
16	5.14	5.81	6.91	7.96	15.34	26.30	28.85	32.00	34.27
17	5.70	6.41	7.56	8.67	16.34	27.59	30.19	33.41	35.72
18	6.26	7.01	8.23	9.39	17.34	28.87	31.53	34.81	37.16
19	6.84	7.63	8.91	10.12	18.34	30.14	32.85	36.19	38.58
20	7.43	8.26	9.59	10.85	19.34	31.41	34.17	37.57	40.00
25	10.52	11.52	13.12	14.61	24.34	37.65	40.65	44.31	46.93
30	13.79	14.95	16.79	18.49	29.34	43.77	46.98	50.89	53.67
40	20.71	22.16	24.43	26.51	39.34	55.76	59.34	63.69	66.77
50	27.99	29.71	32.36	34.76	49.33	67.50	71.42	76.15	79.49
60	35.53	37.48	40.48	43.19	59.33	79.08	83.30	88.38	91.95
70	43.28	45.44	48.76	51.74	69.33	90.53	95.02	100.42	104.22
80	51.17	53.54	57.15	60.39	79.33	101.88	106.63	112.33	116.32
90	59.20	61.75	65.65	69.13	89.33	113.14	118.14	124.12	128.30
100	67.33	70.06	74.22	77.93	99.33	124.34	129.56	135.81	140.17

ν = degrees of freedom.
[a]Adapted with permission from *Biometrika Tables for Statisticians*, Vol. 1, 3rd ed., by E. S. Pearson and H. O. Hartley, Cambridge University Press, Cambridge, 1966.


Probability Density Function
y=chi2(x,14)
95% at 14 df's
0.175
0.131
0.087
0.044
0.000
0.00
6.25
12.50
18.75
25.00


Probability Density Function
y=chi2(x,14)
5% at 14 df's
0.175
0.131
0.087
0.044
0.000
0.00
6.25
12.50
18.75
25.00

1.3 HVPS Design and Packaging Considerations

Rigorous HVPS design requires a team effort that includes electrical, mechanical, materials and systems engineering people. The fundamental concurrent engineering tool to be used by this multi-functional design team is QFD. Through the use of the QFD forms and process, the full set of requirements can be considered together, and technical, cost, and schedule risks areas can be identified. Highlighted problems can often be studied and solved using MTS-DOE methods. Proper implementation of requirements at all conceptual levels of the power supply, from highest level of the system as a whole, down to the level of the individual components and materials used, is the most important task of the design team. The Manufacturing Technology for High Voltage Power Supplies program had as a major goal the development and demonstration of these techniques, and they are presented later in this report.

While the focus of the program was not on electrical design, there are specific, technical considerations that enter into a power supply's overall packaging and electrical designs that are of great importance. Isolating the high voltage circuitry in the supply from its low voltage circuitry is important to minimize noise and coupling. Also, routing of high voltage and low voltage leads should be planned to minimize the number of interconnects. Interconnects represent potential sources of noise, spurious rectifying junctions, and mechanical failure. High voltage leads should be short, and routed to minimize inductance, and the effects of coupled signals.

The high voltage assembly should be designed for the unobstructed flow of the potting material, and the viscosity of the potting material during the pouring and filling process should be considered when laying out the power supply's components, and establishing spacings between components, between components and structural members, and between components and the mold walls. Minimizing bubbles and voids in the high voltage areas is critical to power supply performance and reliability. Potting molds should be designed for free and unobstructed flow of potting material during encapsulation, and for ease of removal from the potted assembly. The mold should be designed with the thought in mind to minimize mechanical strains induced into the potted assembly as the mold is removed -thus avoiding formation of cracks or crack precursors in the materials.

When printed wiring boards (PWBs) are used, adequate spacing between PWB traces carrying different voltages, should be maintained in order to minimize the possibility of arcing and breakdown during operation. The surface of the PWB acts as a natural pathway for conduction, and good adhesion between the potting material and the PWB materials is important. The particular PWB materials used are also important, since the fibers in the PWB mat also represent surfaces along which electrical charge can travel.

The coefficient of thermal coefficient (CTE) of all materials in the assembly should be considered during the design process, along with their compatibility with each other, and their ability to bond to each other, and to the components in the supply. Since

materials selection can affect critical aspects of electrical design, packaging design, component selection, selection of other materials, process selection, and testing, this important design aspect should be considered by the entire multifunctional team, and not just left up to one materials engineer.

Adequate stress relief should be provided for all component leads and wiring. This is particularly true in the case of very fine wires, such as those used in some transformers. The thermal cycling of power supplies during operation has been shown to place such wires under mechanical stress. Under such conditions, stress may be concentrated in a specific area of the wire, which then necks down as a result of grain size change due to stress action, strain hardedning etc. Wire failure is the last step in this process. Finally, thermal analyses should be performed to assure adequate heat transfer in the supply to prevent overheating, followed by material or component failure.

Important electrical design considerations include the use of E-field analyses to reveal potential problems with neighboring circuitry, and potential problems in the supply itself, including excessive voltage stresses. Where necessary, electrostatic shielding of sensitive circuitry in and near the HVPS should be planned in the design. Power supply turn-on and turn-off should be controlled in such a way as to prevent large transient voltages from stressing power supply components or components in circuitry attached to the supply. In the transformer, core saturation at high temperature is an issue that must be considered in the design. For HVPSs powering traveling wave tubes (TWTs), limiting the arc current in the supply to the extent practical is also important to protect the supply's components against damage due to severe voltage transients. A related component issue that affects the design is the stability of voltage divider resistors after output arcing. Also, in such applications it is wise to design the HVPS in such a way as to decouple sensitive I/O signals from the effects of arcing and corona discharge, to the maximum extent possible. HVPSs may be subjected to varying levels of humidity, or even to moisture in some applications. The potential effects of moisture and electrostatic effects on high impedance circuitry must be carefully considered in the electrical design, packaging design, and in the selection of components that may potentially be affected, including connectors.

When HVPSs are used to power TWTs, tube arcing can place severe stresses on the power supply. The design should ensure survivability under under these conditions. Observed effects of TWT arcing on power supplies include the effects on feedback dividers, effects on control circuitry, and arcs in secondary loads resulting from arcing in the primary load.

Voltage stresses must be a primary concern in HVPS design. A wide range of difficulties are created when HVPS designs incorporate high voltage stresses in individual components, or in the packaging design layout. Arcing, corona discharge, and dielectric breakdown are frequenctly observed in HVPSs where high voltage stresses are present. These effects, in turn, can cause intermittent or continuous electrical faults, and they can destroy components and encapsulation materials.

Defect growth in regions of high voltage stress is often observed during operation, and catastrophic breakdown of a portion of the supply is not uncommon.

The presence of high voltage stresses places severe demands and restrictions upon component design, component materials, impregnation and encapsulation materials, and impregnation and encapsulation processes. Careful processing to avoid the formation of voids or bubbles in impregnants and encapsulants is especially critical. The use of heavily filled encapsulants may be necessary to achieve certain thermal conductivity and/or CTE (Co-efficient of Thermal Expansion) properties, however, a high percentage of fillers in the encapsulation material also increases its viscosity. Depending upon the packaging design, this may make it difficult to completely eliminate all voids in the potting in regions of the high voltage stress. Under such conditions, an encapsulation MTS, a mockup of the power supply layout which can be encapsulated and then disected to look for voids in regions of known high voltage stress, is an important step in the design process.

The following set of tables highlight the above discussion and should be used as a reference in the design and/or manufacturing process for HVPSs. Table 4 lists several stress limits for design reference. The conservative limits should be the first design choice. Finally, a test plan to exercise the HVPS via environmental cycling at various operating conditions is critical to establishing long term reliability.

Table 1 ELECTRICAL DESIGN CONSIDERATIONS

E FIELD ANALYSIS

LIMIT ARC CURRENT TO EXTENT PRACTICAL

ELECTROSTATIC SHIELDING OF SENSITIVE CIRCUITRY IN AND NEAR THE HVPS

CONTROLLED TURN-ON/TURN-OFF

CORE SATURATION AT HIGH TEMPERATURE

DECOUPLING OF SENSITIVE I/O SIGNALS FROM EFFECTS OF ARCING AND CORONA

PIN TO CASE VOLTAGE BREAKDOWN OF ACTIVE DEVICES

MOISTURE AND ELECTROSTATIC EFFECTS ON HIGH IMPEDANCE CIRCUITRY

DIVIDER RESISTOR STABILITY AFTER OUTPUT ARCING

Table 2. MECHANICAL DESIGN CONSIDERATIONS

- ISOLATE HIGH VOLTAGE CIRCUITRY FROM LOW VOLTAGE CIRCUITRY
- PLAN ROUTING OF HIGH VOLTAGE AND LOW VOLTAGE LEADS TO MINIMIZE NUMBER OF INTERCONNECTS
- MINIMIZE INDUCTANCE OF HIGH CURRENT LEADS
- DESIGN HIGH VOLTAGE ASSEMBLY FOR UNOBSTRUCTED FLOW OF POTTING MATERIAL
- DESIGN POTTING MOLDS FOR FREE FLOW OF POTTING MATERIAL ANC EASE OF removal FROM THE POTTED ASSEMBLY
- ADEQUATE SPACING FOR DIFFERENTIAL VOLTAGE ON PWBs
- CONSIDER CTE OF ALL MATERIALS IN HV ASSEMBLY
- ADEQUATE STRESS RELIEF FOR LEADS
- DESIGN HV ASSEMBLY FOR REPAIRABILITY
- THERMAL ANALYSIS TO ENSURE ADEQUATE HEAT TRANSFER

Table 3. DESIGN TIPS / CHECK LIST

ENSURE TOTAL IN-SYSTEM PERFORMANCE UNDER ALL POSSIBLE OPERATION CONDITIONS

- PROBLEMS ENCOUNTERED
  - CONTROL LOOP STABILITY FOR ALL COMBINATIONS OF LINE, LOAD AND ENVIRONMENTAL CONDITIONS
  - TURN-ON/TURN-OFF ANOMALIES
  - CORE SATURATION AT MAXIMUM OPERATING TEMPERATURE AND LINE CONDITIONS
  - RANDOM UNWANTED "ON" OR "OFF" COMMANDS
  - INTERMITTENT FAULTS (MUST BE RECONCILED)
  - CONNECTOR ARCING AT ALTITUDE AND COLD TEMPERATURE
  - LOCALIZED HOT SPOTS IN HV ASSEMBLY

ENSURE SURVIVABILITY UNDER ALL POSSIBLE "ABNORMAL" CONDITIONS

- TWT ARCING
  - STACKED OUTPUT VOLTAGES WITHIN LIMITS
  - EFFECT ON FEEDBACK DIVIDER
  - EFFECT ON CONTROL CIRCUITRY
  - SECONDARY LOAD ARCS RESULTING FROM PRIMARY ARC

Table 4. OPERATING STRESS LIMITS

	Conservative Limits	Special Conditions
POWER DENSITY (WATTS/IN^3)	20	>60
MAX TRANSFORMER TEMPERATURE (DEG. C)	125-150	125-150
BULK LINEAR VOLTAGE STRESS (VOLTS/MIL)	50	100
BULK RADIAL UTILIZATION FACTOR	2:1	5:1
BULK MAXIMUM FIELD STRESS (VOLTS/MIL)	100-300	300-100(

2.0 Characteristics Of Encapsulants

2.1 Introduction

The ideal characteristics of a high voltage power supply encapsulant (Table 1 for example) are not found in any single material. The three most common encapsulants, epoxy, silicone and urethane have been categorized in this section according to properties that are significant for use in high voltage applications. Each of the materials has attributes that make it a selectable material; however, performance in the application is necessary to validate the choice.

Encapsulants also have an added difficulty (compared to electrical components as an example) in that it is likely that batch to batch variation (essentially product consistency) will be a factor complicating measurement of material properties. During the course of this program, silicone shipment to shipment "variations" had to be understood and certain characteristic properties identified as useful indicators of consistency before true characterizing of the material could be accomplished. The consistency testing included the need to involve 3rd party testing laboratories because of differences in test methods and equipment at supplier and user sites. Details are addressed in Volume 3 of these guidelines and in the final program report(volume 1).

Table 1

Characteristic	Attribute
1. High Voltage	1. High CIV, CEV; High electric field strength; Corona Resistance
2. High heat Transfer function	2. High thermal conductivity; high electric field strength
3. Low electrical losses	3. High volume / surface resistivities; low dissipation factor; low dielectric constant
4. Adherent	4. Adherent to surfaces of components AND construction materials
5. Processible	5. Low viscosity and surface tension; adequate pot-life / Gel time; reasonable cure conditions
6. Repairable	6. Reasonably removed; replacement does not compromise function, quality
7. Mechanical Adequacy	7. Variable depending on function / requirements

2.2 Material Comparisons

Table 2 qualitatively compares key properties of the materials. As noted, fillers affect thermal performance. They also affect other properties such as CTE. For example, a common filler for silicone is Alumina which reduces CTE while improving thermal conductivity. Table 3 provides further comparison details on some specific epoxy and urethane materials that have been considered for high voltage applications.

Table 2

	MATERIAL				
PARAMETER	IDEAL	RIGID EPOXY	FLEXIBILIZED EPOXY	FLEXIBILIZED POLYURETHANE	SILICONE
VISCOSITY	LOW	LOW	LOW TO MEDIUM	MEDIUM	MEDIUM TO HIGH
VOLTAGE CAPABILITY	HIGH	HIGH	LOW	LOW	MEDIUM
REPAIRABILITY	EASY	DIFFICULT	FAIRLY EASY	EASY	EASY
GLASS TRANSITION TEMPERATURE	LOW	MEDIUM TO HIGH	MEDIUM	MEDIUM TO LOW	VERY LOW
MODULUS	LOW	HIGH	MEDIUM TO LOW	LOW	VERY LOW
CTE	LOW	HIGH	VERY HIGH	VERY HIGH	VERY HIGH
ELECTRICAL LOSS	LOW	LOW TO HIGH	MEDIUM TO HIGH	MEDIUM TO HIGH	HIGH
ADHESION	HIGH	HIGH	MEDIUM TO HIGH	MEDIUM TO HIGH	LOW
THERMAL CONDUCTIVITY	HIGH	LOW TO HIGH*	LOW TO HIGH*	LOW TO MODERATE*	LOW TO MODERATE*

*HEAT TRANSFER CAPABILITY IS A FUNCTION OF FILLER EMPLOYED

Table 3

MATERIAL	FUNCTION AT HIGH ELECTRIC STRESS	HIGH HEAT TRANSFER	LOW ELECTRICAL LOSSES	ADHERENT	PROCESSIBLE	REPAIRABLE	MECHANICAL ADEQUACY
EPON 825/HV	X		X	X	X		X
SCOTCHCAST 280			X	X	X		X
SCOTCHCAST 281		X		X	X		X
SCOTCHCAST MR283 F-025		X	X	X	X		X
SCOTCHCAST MR283 F-100		X		X	X		X
URALANE 5753				X	X	X	X
STYCAST 2651		X		X	X		X
STYCAST 2850FT		X	X	X	X		X
RICOTUFF LV (P)*	X		X	X	X		X
RICOTUFF LV (U)*	X		X	X	X		X
PR 1665				X	X	X	X
DA3C	X		X	X	X		X
HRG-3/A2			X	X	X	X	X
HR6-3/A0			X	X	X	X	X
CYCLOALIPHATIC EPOXY	X		X	X	X		X
CY225	X		X	X	X		X

*P — POSTCURED U — NOT POSTCURED

2.3 Standard Test Methods

Table 4 provides references for the configuration and test methodologies used in measuring material characteristics. Improvisation may be necessary in some cases - particularly associated with Silicones - to obtain more meaningful comparisons of materials. For example, temperature cycling is generally an excellent indicator of long term reliability. A test program to perform specific tests during (or after) a temperature cycle program could enhance material comparisons.

Table 4

TEST	DATA	SPECIFICATION	SPECIMEN CONFIGURATION	TEST CONDITIONS
ADHESIVE STRENGTH TO AL, EPOXY AND/OR POLYIMIDE GLASS LAMINATE, FUSED Sn/Pb SOLDER	LAP-SHEAR STRENGTHS	ASTM D1002	1 IN. x 1/2 IN. x 0.005 IN. OVERLAP	ROOM TEMPERATURE 0.050 IN./MIN.
T-PEEL	PEEL	ASTM D1876	1 IN. W x 12 IN. L	ROOM TEMPERATURE 0.050 IN./MIN.
HARDNESS	SHORE VALUE (INITIAL AND 10 SEC DWELL)	ASTM D2240	HOCKEY PUCK	ROOM TEMPERATURE
SPECIFIC GRAVITY	SPECIFIC GRAVITY VALUE	ASTM D792	ANY	ROOM TEMPERATURE
MOISTURE EFFECT	EXPOSURE AND RECOVERY	MIL-STD 202 METHOD 106		-
DIELECTRIC STRENGTH	DIELECTRIC STRENGTH	ASTM D149	2 IN. D	ROOM TEMPERATURE, ~500V/SEC
VISCOSITY	VISCOSITY	ASTM D2393	≤500 ML	ROOM TEMPERATURE AND 160°F
IZOD IMPACT	IZOD IMPACT	ASTM D256	1/2 x 1/2 x 2 1/2 IN.	ROOM TEMPERATURE
SHEAR STRENGTH	SHEAR VALUES			
DENSITY	DENSITY VALUES	ASTM D792 D1875		
THERMAL CONDUCTIVITY	CONDUCTIVITY VALUES	ASTM F433	2 IN. DIAMETER x 1/4 IN. THICK (2 IN. D x 1/4 IN. T)	-
THERMAL COEFFICIENT OF EXPANSION	CTE	HAC (TMA) OR ASTM E83 (DILATOMETER)	1/2 IN. D x 1/4 IN. T	-70 TO +200°C
ENTHALPY	ΔH	HAC (DSC)	1/2 IN. D x 1/4 IN. T	-70 TO 200°C
GLASS TRANSITION TEMPERATURE	Tg	HAC (TMA/DSC)	1/2 IN. D x 1/4 IN. T	-70 TO 200°C
VOLUME/SURFACE RESISTIVITIES	OHM-CM (IN.); OHM/□ AS FUNCT T°C	ASTM D257	4 IN. D x 0.040 IN. T	ROOM TEMPERATURE 500 VOLTS
DIELECTRICAL CONSTANT	DIELECTRIC CONSTANT AS FUNCT T°C AND FREQ	ASTM D150 (NO CONDITIONING)	2 IN. D x 0.040 IN. T	ROOM TEMPERATURE 1 VOLT RMS 1 kHz - 1 MHz
DISSIPATION FACTOR	DISSIPATION FACTOR AS FUNCT T°C AND FREQ			
TENSILE STRENGTH AND ELONGATION	YIELD AND ULTIMATE STRENGTHS/ ELONGATION	ASTM D638	3/4 IN. x 7 IN. x 1/4 IN. DOGBONE	ROOM TEMPERATURE 0.050 IN./MIN.
TENSILE MODULUS	TENSILE MODULI			
ELECTRIC FIELD STRENGTH	V_{BD}			
CORONA CHARACTERIZATION	CIV; DEV DISCHARGE ENERGY			

3.0 Test Parameters Of Components

Manufacturing reliable HVPSs requires continuous on-going test programs (and/or burn-in/conditioning programs) of high voltage components.

The tables in this section list key parameter tests of discrete components used in high voltage power supplies. Descriptions and references are provided. Where test methods are not specified, users frequently develop their own procedures and/or modify existing Mil-Spec, ASTM procedures.

COMPONENT — XFMR, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR	CIV, CEV AT 60 Hz, DC AND Fo; DISCHARGE ENERGY AT 60 Hz AND DC		ASSESS QUALITY OF HV ISOLATION SYSTEMS
TEMP RISE UNDER LOAD	$\Delta T°(S)$ FOR WINDINGS AND CORE AS FUNCT OF LOAD AND F_{OP}	MIL-T-27	ASSESS THERMAL DESIGN AND CONTROL TECHNIQUES
LIFE UNDER LOAD AT F_{OP}	ΔCIV, ETC AS FUNCT OF TIME; TIME TO FAILURE		DET PROBABLE OP LIFE TIMES VS RQMTS
THERMAL SHOCK RESISTANCE	ΔCIV, ETC AS FUNCT OF NO. CYCLES		DET EFFECTS OF THERMO-MECH STRESS ON HV ISOLATION QUALITY
MOISTURE	ΔCIV, ETC; Δi LEAKAGE		GEN QUALITY HV INSULATION
ATTITUDE EFFECTS	ΔCIV		INTEGRITY OF HV INSULATION
CONSTRUCTION REVIEW			CONSTRUCTION QUALITY TECHNIQUES

COMPONENT — XFMR, HV

TEST	DATA	METHOD	PURPOSE
STANDARD XFMR TESTS			
L_{PRIM}	SEE TEST		VERIFY DESIGN RQMTS
I_{EXCIT}	SEE TEST		VERIFY DESIGN RQMTS
$L_{LEAKAGE}$	SEE TEST		VERIFY DESIGN RQMTS
V/TURNS RATIOS	SEE TEST		VERIFY DESIGN RQMTS
R_{DC}	SEE TEST		VERIFY DESIGN RQMTS
$C_{DISTRIB}$	SEE TEST		VERIFY DESIGN RQMTS
INSUL RESIST	SEE TEST		VERIFY DESIGN RQMTS
DWV	SEE TEST	MIL-T-27	VERIFY DESIGN RQMTS
SHIELDING RATIO	SEE TEST	MIL-T-27	VERIFY DESIGN RQMTS
RESONANCE OPEN CKT SHORTED SEC	SEE TEST		VERIFY DESIGN RQMTS
MECHANICAL STRESS — SHOCK — VIBRATION	ΔCIV, ETC; ΔPARAMETRICS	MIL-STD-202	ASSESS MECH INTEGRITY OF DESIGN

COMPONENT — XFMR, HV

TEST	DATA	METHOD	PURPOSE
$V_{INDUCED}$	ΔCIV, ETC; EVIDENCE OF ELECTRICAL BRKDN	MIL-T-27	DESIGN MARGIN OF HV ISOLATION
IMMERSION (H_2O)	ΔCIV, ETC; $\Delta I_{LEAKAGE}$	MIL-STD-202	QUALITY ELECTRICAL INSULATION

COMPONENT — HV RECTIFIER DIODES

TEST	DATA	METHOD	PURPOSE
CORONA CHAR	CIV, CEV DC V_R		CORONA EXISTENCE AFFECTING PERFORM/LIFE
SWITCHING TIMES	TURN-OFF/ON TIMES	MIL-STD-750C	DATA TO ESTIMATE OP FREQ LIMITS; INFO FORMATTING
POWER DISSIP AS FUNCT FREQ AND DUTY CYCLE	ΔT°, ΔV AS FUNCT F_O AND DUTY CYCLE		ESTABL FREQ/DUTY CYCLE LIMITS
DET HEAT TRANSFER MECHANISMS	ΔT° BODY AND LEADS VARIOUS OP CONDITIONS		AID IN DESIGN/MATLS FOR THERMAL CONTROL
MATCHING CHAR — TURN-OFF — I_R AT V_R OP — V_F AT I_F OP	TURN-OFF TIME; I_R; V_F		IDENT SIGNIF. PARAMETERS WHEN DEVICES USED IN SERIES
V_F AS FCN I_F AND T°C	SEE TEST		PREDICT OPERATE LOSSES
I_R AS FCN V_R AND T°C	SEE TEST		ASSESS V_R DISTRIB IN SERIES CONFIG
V_{BD}	SEE TEST	MIL-STD-750C	IDENT OP LIMITS V_R
THERMAL SHOCK EFFECTS	ΔV_F; ΔI_R; ΔCIV DC		STRUCTURAL INTEGRITY
CONSTRUCTION REVIEW			CONSTRUCTION QUALITY, DEVICE DESIGN
FAILURE ANALYSES			SITE LOCATION; POSS. MECHANISMS
LEAD PULL STRENGTH	ΔV_F AFT PRE LOAD; LOAD TO FAILURE	MIL-STD-750C	MECHANICAL INTEGRITY
HTRB	ΔI_R; ΔV_F; FAILURE RATES	MIL-STD-750C	DEVICE QUALITY

COMPONENT — CAPACITORS, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR	CIV, CEV AT 60 Hz, DC AND F_{OP} DISCHARGE ENERGY AT 60 Hz AND DC		ASSESS GEN HV QUALITY AND PROBABLE LIFE TIME
DC LIFE -X V (X ≥ 1)	ΔCIV, ETC, $\Delta I_{LEAKAGE}$ DC AS FCN TIME; TIME-TO-FAILURES		SEE ABOVE
INSULATION QUALITY	$I_{LEAKAGE}$ AS FUNCT V_{DC} AND T°(C)		SEE ABOVE
THERMAL SHOCK EFFECTS — 25 CYCLE — EXTENDED CYCLE	ΔCIV, ETC; $\Delta I_{LEAKAGE}$ AT V_{DC}; ΔC; ΔDF		EFFECTS OF THERMO MECH STRESS ON HV ISOLATION QUALITIES; DEVICE INTEGRITY
ATTITUDE EFFECTS	ΔCIV, ETC		QUALITY OF CONSTRUCTION
MOISTURE EFFECTS	ΔCIV, ETC; $\Delta I_{LEAKAGE}$		QUALITY INSULATION SYSTEM
CONSTRUCTION REVIEW			DESIGN METHODS; CONSTRUCTION QUALITY
FAILURE ANALYSES			IDENT FAILURE SITES;

COMPONENT — CAPACITORS, HV

TEST	DATA	METHOD	PURPOSE
STANDARD TESTS			
— C, DF AS FNC FRQ AND T°C	SEE TEST	MIL-STD-202	DESIGN/FUNCTION VERIFICATION
— DWV	SEE TEST	MIL-STD-202	DESIGN/FUNCTION VERIFICATION
— VCC	SEE TEST	MIL-STD-202	DESIGN/FUNCTION VERIFICATION
— TCC	SEE TEST	MIL-STD-202	DESIGN/FUNCITON VERIFICATION
— V_{BD}	SEE TEST	MIL-STD-202	DESIGN/FUNCTION VERIFICATION
— IMMERSION (H_2O)	$\Delta I_{LEAKAGE}$ AT V_{DC}	MIL-STD-202	DESIGN/FUNCTION INTEGRITY

COMPONENT — RESISTORS, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR FOR R ≥ 100M OHMS DC	CIV, CEV AND DISCHARGE ENERGIES		PRODUCT QUALITY; SUSEPT TO CORONA DEGRAD
V_{BD} — END-TO-END DC	V_{BD}		ESTAB USE LIMITS
STABILITY AT V_{RATED}	ΔR AS FUNCT TIME		DEVICE STABILITY
LIFE AT X·V_{RATED} (X ≥ 1)	ΔR AS FUNCT TIME	MIL-STD-202	ESTIMATING LIFE TIME AND STABILITY
THERMAL SHOCK EFFECTS	ΔR AS FUNCT NO. CYCLES		ASSESS THERMO-MECHANICAL INTEGRITY
MOISTURE EFFECTS	ΔR		ASSESS MOISTURE SUSEPT
VCR	SEE TEST		PERFORMANCE/APPLICATIONS
TCR	SEE TEST	MIL-STD-883	INDICATORS
R_{RATED} VS TOL	SEE TEST		PRODUCT QUALITY
LEAD STRENGTH	ΔR DUE TO PRE LOADING; LOAD TO FAILURE		PRODUCT QUALITY; MECHANICAL INTEGRITY
CONSTRUCTION REVIEW			DESIGN DETAILS; CONSTRUCTION QUALITY
FAILURE ANALYSES			FAILURE SITES; POSS MECHANISMS

COMPONENT — CONNECTOR, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR — GND PLANE/SHELL — PIN-TO-PIN	CIV, CEV AT 60 Hz, DC AND F_{OP}; DISCHARGE ENERGY AT 60 Hz AND DC		ASSESS GEN HV QUALITY DESIGN/MATERIALS
VOLTAGE WITHSTAND — GND PLANE/SHELL — PIN-TO-PIN DC	X, V_{RATED} (X ≥ 1 ≤ 2); ΔCIV, ETC; $\Delta I_{LEAKAGE}$		SEE ABOVE
ALTITUDE EFFECTS	ΔCIV, ETC AT ALTITUDE		DESIGN AND/OR SEAL EFFECTIVENESS
MOISTURE EFFECTS	ΔCIV, ECT; $\Delta I_{LEAKAGE}$		QUALITY HV MATERIALS
MECHANICAL CHAR — IMPACT RESIST — CRUSH STRENGTH	FORCES/LOADS TO DAMAGE		MECH ADEQUACY
LIFE AT X, V_{RATED} MULTIPIN ONLY (X ≥1)	SEE VOLTAGE		
R MATING	R VALUES FOR MATED PINS	4-TERMINAL	PRODUCT QUALITY
CONSTRUCTION REVIEW			DESIGN DETAILS; MAT'LS; CONSTRUCTION QUALITY
FAILURE ANALYSES			FAILURE SITES; POSS MECHANISMS

COMPONENT — CONNECTOR, HV

TEST	DATA	METHOD	PURPOSE
THERMAL SHOCK EFFECTS — SHELL AND MULTIPIN ONLY	ΔCIV, ETC; ΔR MATING		THERMOMECH STRESS RESPONSE TO HV ISOLATION INTEGRITY AND CONTACT MATING QUALITY

COMPONENT — SPARK GAP, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR	CIV, CEV, DISCHARGE ENERGY DC		ESTABL Δ BETWEEN CIV AND TRIGGER V_{DC}; AFFECTS ON V_{OP}
TRIGGER VOLTAGE	V_{DC} AT TRIGGER (VBD)		PRODUCT QUALITY/ UNIFORMITY
DISCHARGE EFFECTS	ΔCIV; ΔV_{BD} AS FUNCT OF NO. OPERATIONS/TOT DISCHARGE ENERGY		EFFECTS OF OPERATIONS ON V_{BD}
LEAD PULL	ΔCIV; V_{BD} AFT PRELOAD; LOAD TO FAILURE		MECHANICAL INTEGRITY
LEAK TEST	SEE ABOVE		SEE ABOVE
CONSTRUCTION REVIEW			DESIGN DETAILS/MAT'LS; CONSTRUCTION QUALITY

COMPONENT — CABLES, HV

TEST	DATA	METHOD	PURPOSE
CORONA CHAR — TO GND PLANE	CIV, DEV, DISCHARGE ENERGY AT 60 Hz AND DC		ESTABL GEN QUALITY HV INSULATION
V_{BD} TO GND PLANE RT ELEV TEMP	V_{BD} DC THRU INSULATION		ESTABL V_{OP} MAX AND AS AFFECTED BY TEMP
LIFE X, V_{RATED} TO GND PLANE ($X \geq 1$)	ΔCIV AS FUNCT OF TIME; TIME TO FAILURE		ESTABL V_{OP} LIMITS
MOISTURE EFFECTS	ΔCIV ETD; $\Delta I_{LEAKAGE}$		MOISTURE SUSCEPT; GEN QUALITY
ALTITUDE EFFECTS	ΔCIV AT ALTITUDE		GEN QUALITY; SUSCEPT TO LOW PRESSURES
INSULATION QUALITY	$I_{LEAKAGE}$ FCN V_{DC} AND T°C		QUALITY INDICATOR
MECHANICAL CHAR — TENSILE STRENGTH — CUT-THRU RESIST	SEE TEST		ASSESS MECHANICAL QUALITIES
CONSTRUCTION REVIEW			IDENT DESIGN/MAT'L DETAILS

4.0 Environmental Stress Testing

The significance of environmental stress testing cannot be overstated for airborne applications. As a screening technique for verification of manufacturing reliability, as a comparative tool to assess the efficacy of design changes or as a measure of long term performance, this type of testing will serve as an extremely useful diagnostic tool.

In the course of the HVPS MANTECH program, reliable performance was verified with approximately 75 cycles (30 days of continuous exposure) applied to various encapsulated assemblies. As a screening for infant failures, all hardware produced for the ALQ-135 Countermeasures System undergoes four cycles of testing:

The Dynamic Environmental Stress Screening procedure consists of four (4) thermal cycles. Refer to Figure 1 for temperature profile. The HV is enabled after 5 minutes into the COLD to HOT transition and stays on the duration of HOT soak. Loading, based on typical TWT information, is applied whenever HV is enabled. If at any time there is a HV fault, the HV Assy will be disabled for the remaining duration of that cycle. It then will try to be re-enabled the next cycle. The fault detection will simulate the same fault control as in the LRU (3X fault). Total time for 1 cycle is 480 minutes.

The liquid cooled Cold plate temperature is kept at +35° C whenever High Voltage and loads are applied.

<u>Setup</u>

Loads(based on typical TWT information):

Bcath	10ma	
Bcol1	70ma	
Bcol2	150ma	
Acath	200mapk	5%D.C 2khz rate
Acol	1.26Apk	5%D.C 2khz rate

Coolant control: Adequate to maintain the cold plate temperature at +35° C/± 5° C.

Temperature:

Cold -55° C +/- 5° C

Hot +71° C +/- 5° C

Transition time 3 to 5° C/min

Test

Apply thin layer of thermal grease to bottom of HV Assy. Ensure complete surface is covered.

Mount HV Assy to base-plate in chamber using torque tool. Torque middle two (2) jackscrews first using 15 in/lbs, then torque remaining four (4) jackscrews using 8 in/lbs.

Mate all necessary connectors (HV, INV drive, feedback control) to the HV assy.

Verify operation of HV Assemble by enabling it for five (5) minutes at ambient (25° C) temperature utilizing loads as described in setup.

Proceed to run 4 cycles of ESS. Refer to Figure 1.

RECORD signature/employee # and date on MOT under Dynamic Environmental Stress Screening operation indicating 4 cycles of dynamic ESS had been completed.

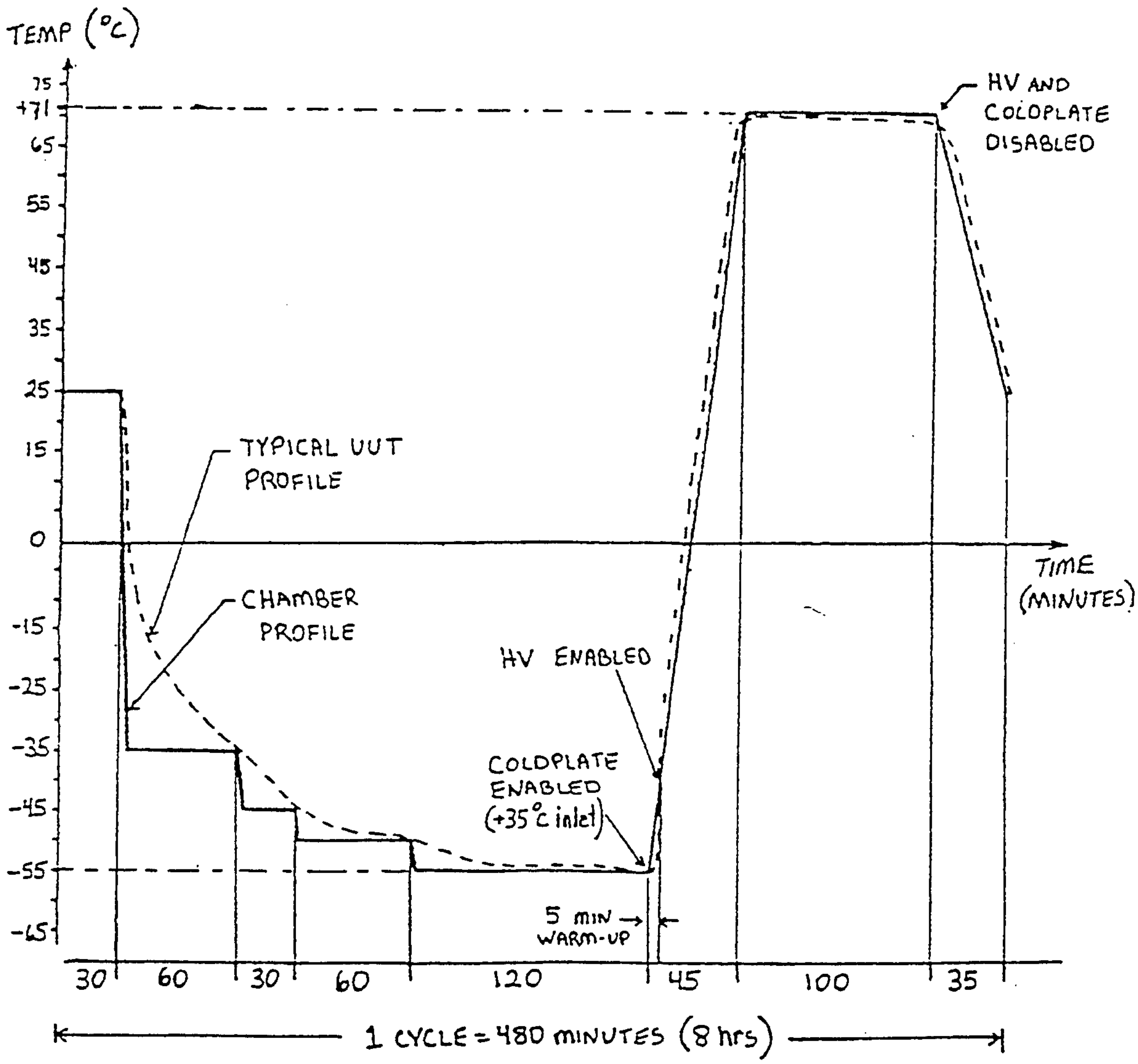


FIGURE 1
TEMPERATURE PROFILE

STEP	SET PT (°C)	TIME	NEXT STEP	REPEAT
1	23	00:01	2	0
2	25	00:01	3	0
3	25	30:00	4	0
4	-35	00:01	5	0
5	-35	1:00:00	6	0
6	-45	00:01	7	0
7	-45	30:00	8	0
8	-50	00:01	9	0
9	-50	1:00:00	10	0
10	-55	00:01	11	0
11	-55	2:00:00	12	0
12	71	00:01	13	0
13	71	1:40:00	14	0
14	23	00:01	1	3
*15	23	1:00:00	16	0
16	23	8:00:00	17	0
17	23	1:00:00	00	0

TABLE 1

CHAMBER PROGRAMMING

(TENNEY ASSET #67752)

* NOTE: UNIT MAY BE REMOVED HERE

5.0 Cost-Benefits and Design Of Experiments (DOE)

5.1 Introduction

In a manufacturing environment it is essential that the benefits associated with the costs to determine material properties, component performance, operating lifetimes of equipment, etc. be established prior to the start of a test program. This analysis essentially involves determining the sample size and test duration required to establish attributes with a preselected confidence level. It is essential also that the results of any experimental test program be validated and reproducible by other suppliers, contractors or interested organizations. Conclusions must be sound in accordance with proven statistical techniques.

To determine such things as sample size when there is no existing reliable data, several assumptions must be made. Factors such as type of data distribution and repeatability of a test method (including the equipment and operator) must be estimated in order to develop a reasonable plan. Such things as accuracy of test results can be assured by verifying the results from a primary test site at a secondary test site. If there is significant disagreement between the two, a third or referee test site may be needed. It should be assumed that material and component properties or some transformation of them (i.e. log or inverse) are distributed normally. However lifetime data (MTBF) is assumed to be distributed exponentially. These initial assumptions must then be verified and modified as necessary as the first test results are evaluated.

5.2 Material testing

For initial test runs assume that the test method is repeatable within +/- 10 percent of the true mean (μ) value and that if the appropriate number of samples are tested, the average value (x-bar) will be within +/- 2 percent of the true mean.

To determine the appropriate sample size, the following standard can be used:

$$n = [(z * \sigma)/a]^2$$

(equation 1)

where
- n= number of samples
- z= critical value from the Standard Normal Distribution corresponding to the chosen confidence interval
- a= margin of error for μ the true mean for an infinite sample size
- σ= sigma, the true standard deviation for the population from which the samples are drawn

Since sigma is the standard deviation of an infinite population and therefore unknown, it must be estimated by using the fact that in a normal distribution; 68 percent of the population will fall within +/- 1σ, 95 percent of the population will fall into +/- 2σ, and 99.7 percent fall into the +/- 3σ range.

Taking a conservative approach, a is estimated as the total range of test values (R) divided by 4. The range is divided by 4 rather than 6 since there is so little gain in probability between +/- 2σ and +/- 3σ. Dividing by 6 then, might define an insufficient sample size. Especially for the initial attempts, it is better to err on the side of caution. Thus equation 1 becomes:

$$n = [(R * z)/(4 * a)]^2$$

(equation 2)

At this point testing costs should be estimated and compared with the benefits to be achieved by the program. If the sample size n is prohibitively large, a different set of parameters may need to be established. For values of n at other conditions, see Tables 8-1 and 8-2.

Once the initial testing is complete it will be necessary to reevaluate any preliminary assumptions. If the sample range is greater than 20% of the sample average, it would be desirable to examine the test method, equipment, technique, etc., to determine if there are any attributable causes for the sample variation. If any cause of variance can be identified, it should be corrected and another set of samples run. If attributable cause cannot be found, then the initial assumption, that the range is within + 10% of the mean, must be rejected. If any known attributable cause is not eliminated, then the set will not be random and cannot be used to approximate a normal distribution. If the testing shows a lesser variation than assumed, the number of samples necessary can

be reduced or a higher confidence level assigned. 42 Once the testing is complete for any given parameter, the sample average (x-bar) and sample deviation (S) will be calculated. These results are a measure of the precision of the test method and are denoted as "within" calculations. For further sample size calculations the sample deviation (S) should be substituted for the standard deviation (σ) in equations 1 and 2.

5.3 Component Testing

As stated earlier, component parameter testing should be conducted based on a normal statistical distribution, thus sample size estimates etc. are calculated as stated above for material properties.

One of the most significant attributes of any component or system is its working life or Mean Time Between Failure (MTBF). Since this life data is usually not normal in distribution, the assumptions and equations used above are no longer applicable. Instead life test data of high voltage equipment should be assumed to follow a Weibull distribution. For the initial estimations, however, the data is assumed to follow an exponential distribution (a Weibull distribution having shape parameter β=1) to simplify some of the calculations.

To estimate the number of samples required for life testing, the equation is:

$$r = n * p \qquad \text{(equation 3)}$$

wherer = the number of failures
n = the number of samples
p = the proportion of failure = $1 - e^{(-\lambda T)}$
T = the time of test termination
$\lambda = (\mathrm{MTBF})^{-1}$

Since, again, none of these parameters are known, it is essential to assume preliminary values. To achieve a reasonable confidence in the estimated MTBF, it is necessary to observe a high number of failures. To accomplish this, either a large number of samples must be tested or the failure proportion term must be made large by making T larger. If the test items are expensive and/or difficult to obtain, increasing T is the more practical method. Equation 3 should be used to estimate cost tradeoffs of n and T for an estimated or required MTBF.

TABLE 8-1 SAMPLE SIZE AT VARIOUS RANGE AND ERROR VALUES

z= 1.65 (90% confidence)

Range as a percent of μ

a as % μ	\R a\	5%	10%	20%	25%	50%	100%
	1%	4.3	17.0	68.1	106.3	425.4	1701.6
	2%	1.1	4.3	17.0	26.6	106.3	425.4
	3%	0.5	1.9	7.6	11.8	47.3	189.1
	4%	0.3	1.1	4.3	6.6	26.6	106.3
	5%	0.2	0.7	2.7	4.3	17.0	68.1
	6%	0.1	0.5	1.9	3.0	11.8	47.3
	7%	0.1	0.3	1.4	2.2	8.7	34.7
	8%	0.1	0.3	1.1	1.7	6.6	26.6
	9%	0.1	0.2	0.8	1.3	5.3	21.0
	10%	0.0	0.2	0.7	1.1	4.3	17.0
	11%	0.0	0.1	0.6	0.9	3.5	14.1
	12%	0.0	0.1	0.5	0.7	3.0	11.8
	13%	0.0	0.1	0.4	0.6	2.5	10.1
	14%	0.0	0.1	0.3	0.5	2.2	8.7
	15%	0.0	0.1	0.3	0.5	1.9	7.6
	20%	0.0	0.0	0.2	0.3	1.1	4.3
	25%	0.0	0.0	0.1	0.2	0.7	2.7

TABLE 8-2 SAMPLE SIZE AT VARIOUS RANGE AND ERROR VALUES

z= 1.96 (95% confidence)

Range as a percent of u

	\R a\	5%	10%	20%	25%	50%	100%
a as % u	1%	6.0	24.0	96.0	150.1	600.3	2401.0
	2%	1.5	6.0	24.0	37.5	150.1	600.3
	3%	0.7	2.7	10.7	16.7	66.7	266.8
	4%	0.4	1.5	6.0	9.4	37.5	150.1
	5%	0.2	1.0	3.8	6.0	24.0	96.0
	6%	0.2	0.7	2.7	4.2	16.7	66.7
	7%	0.1	0.5	2.0	3.1	12.2	49.0
	8%	0.1	0.4	1.5	2.3	9.4	37.5
	9%	0.1	0.3	1.2	1.9	7.4	29.6
	10%	0.1	0.2	1.0	1.5	6.0	24.0
	11%	0.0	0.2	0.8	1.2	5.0	19.8
	12%	0.0	0.2	0.7	1.0	4.2	16.7
	13%	0.0	0.1	0.6	0.9	3.6	14.2
	14%	0.0	0.1	0.5	0.8	3.1	12.2
	15%	0.0	0.1	0.4	0.7	2.7	10.7
	20%	0.0	0.1	0.2	0.4	1.5	6.0
	25%	0.0	0.0	0.2	0.2	1.0	3.8

6.0 Database

At the beginning of the program, it was anticipated that a significant amount of detailed experimental data of various types would be collected. Consideration was given to providing this data in the form of a computerized database that would allow establishing a consistent body of data, thus providing direct comparisons between candidates and candidate approaches.

It was believed that, once the database had been established, it would be possible to allow off-site users to have access to the data, by distributing to them at regular intervals updates to the database in an easily readable format. Not anticipating the rapid growth of internet and other readily available schemes, we considered that distribution by floppy disk or compact disk would be ideal, in the event that some users might not be able to go on-line. However this data was distributed, it was hoped users would be able to search, sort, format, analyze, and display the data in any way that they wished.

It was also envisioned that the database administrator could solicit from other workers additional data that would extend or complement that already in the database, and then add this new data to the database and distribute the result. Such a datatabase could be a living document that could serve as a continually updated resource for all HVPS manufacturers.

Therefore, a task was initiated to study the issues involved in databasing for HVPS design and manufacturing. The objective of this activity was to determine what sort of software would be needed to document, format, search, sort, analyze, and display the following types of data:

- Material properties
- Component properties
- Design data
- Packaging approaches
- MTS projects and results
- Test methods
- Processing parameters

The first step toward this goal was to determine whether or not any commercial database software was available that would provide the features that we thought were necessary. To do this, the following listing of general requirements was established to judge the database software:

- Data input allowed
- Editorial input allowed
- Customizable to program needs
- Easy editing

- Sorts and ranks
- Tabulated displays
- Graphical displays
- Can input data already in graphical or tabulated form
- Can take data from an existing format, mingle it, and redisplay only its independent variables
- Database supplier willing to maintain the new database
- Loadable into PC
- Can compare more than two items simultaneously (e.g. materials, components, and packaging)
- Test values referenced by method, with an area for description and comments
- Multiple user capability
- Reliable and stable database supplier
- Bulletin board access

Sorting and ranking are of course key capabilities of a databasing program, and we wanted to to ensure that the software selected allowed the greatest possible flexibility in doing this. As an example, suppose that a set of materials were tested for a variety of physical, mechanical, electrical, and processing properties. Such properties might include:

- Dielectric strength
- Dielectric constant (1 kHz to 1 Mhz)
- Volume resistivity
- Dissipation factor (1 kHz to 1 Mhz)
- hardness
- Thermal conductivity
- Tensile strength
- Elongation
- Lap-shear
- T-peel
- Decomposition temperature
- Glass transition temperature
- Coefficient of thermal expansion
- Work life under normal processing conditions
- Viscosity
- Izod impact strength

A large number of materials might be tested for these properties, and the selected database would have to allow all of this data to be entered into it. The database should then be very flexible in allowing subsets of this data to be abstracted, processed, and displayed. For example, if dielectric constant was the property of interest, the database should allow only the dielectric constant value data for each candidate to be abstracted. Then, the database should allow data processing on that subset of the data. In our example, we might wish to categorize and list the materials in the database in the order of increasing dielectric constant.

Twelve data bases were evaluated against these criteria, and they are shown in the table below. Here, the column labelled "entries" indicates the number of entries that the program allowed for each database. The column labelled "update" indicates the number of times per year that the database program is updated by its supplier. The column labelled "format" shows how the software is supplied to the user. The column labelled "customizing" shows whether or not the supplier allows it to be customized in a flexible way to provide the various formats required for the HVPS application.

Database	Entries	Update	Format	Customizing
Cen Base	>16,000	4x/yr	CD ROM	Yes
Int'l Plastics Sector	~12,700	4x/yr	Disk	No
Plaspec	~11,000	6x/yr	On line	No
Eng Design Database (GE)	~500		On line	No
Polyfacts (DuPont)	~200		on line	No
Eng Properties on Screen (EPOS)	~600		Disk	No
Campus (Mobay)	~150		Disk	No
Campus (BASF)	~150		Disk	No
Percept	~12,500	No	Disk	Yes (CAE)
Plastics Design Library	~50	No	Hard Copy	No
Fast Focus (Hoechst Celanese)	~200		Disk	No
Thermofile (Thermofil)	~450		Disk	No

Of all of these commercially available databases, only the Cen Base software offered the desired set of capabilities, including a large number of possible entries, regular software updates by the manufacturer who would agree to add our data to his database and distribute the updated database to the user community, software available on an easily mailed electronic format, and the ability to freely customize the database. Appendix 2-1 contains additional information about the Cen Base program.

While we were able to select the best database software from those available, it proved infeasible to actually implement this databasing concept. This was because uncertainties in future funding make it impossible to keep the database current, a failing that would render it obsolete and useless.

Quality Function Deployment for High Voltage Power Supplies

Appendix 2-1

THE EVALUATION FORMS AND THEIR USE IN THE QFD REVIEW

1.0 Introduction

The performing of a QFD Review as the first step in designing of a High Voltage Power Supply is intended to achieve a power supply whose manufacturability and associated quality is enhanced as a result of the QFD. In support of these goals, the QFD Review offers the following benefits -

- o means to assure that the requirements of the power supply are adequately defined.
- o assists in identifying and making choices at each level of the design and development process.
- o serves as a map showing -
  - relationships between the various elements of the power supply and their function
  - conditions where interactions between elements of the power supply and between these elements and their environments may affect behavior
  - potential problems within the design and its construction
  - benefits which can result when the choices and selections are linked via the QFD process
- o documented results function as a history of the design and development process.

In the following sections each of the forms comprising the QFD will be described and methods for their use presented.

2.0 Descriptions of the QFD Forms.

In this section each of the forms used in the QFD analysis are briefly described in terms of its function. For many of the forms the form title is self descriptive of its purpose.

The forms are divided into three (3) catagories -

1 - Requirements vs. Methods of Achievement Forms
2 - Experiment and Analyses Forms
3 - Worksheets and Other Forms

Following are the descriptions of the 25 forms in the three (3) catagories comprising the QFD.

2.1 Requirements vs. Method of Achievement Forms

- Figure 1. - HVPS Requirement vs. Design. Basic Form.

This would typically be the first form used in the QFD analysis and is typical of the Requirements vs. Methods of Achievement (WHAT vs. HOW) forms. This form is used to evaluated and compare Candidate Designs in terms of their capabilities to meet the Requirements of the HVPS. This form is intended to be used for both conceptual design and detailed design candidate evaluations.

Figure 2 - HVPS Requirements vs. Design. Extended Form
Expanded Basic

This form is similar in format and purpose to Figure 1. It differs only in that it allows more specific requirements entries under each of the general requirements.

Figure 3. - HVPS Requirements vs. Design. Extended Form,
Detailed.

This form is similar in purpose to Figure 1. It differs in that specific requirements are identified for each of the general requirements.

Figure 4. - HVPS Requirements vs. Design. Open Form.

With this form, the user provides all of the requirement listings.

Figure 5. - Packaging Elements vs. Candidate Designs.
Basic Form.

This form is intended to evaluate specific physical characteristics (Packaging Elements) of candidate designs in order to establish feasibilities of translating concepts and paper details into hardware.

Figure 6. - Packaging Elements vs. Candidate Designs. Open Form.

This form is similar in purpose to Figure 5. Here the user provides all of the packaging element details.

Figure 7. - Component Requirements vs. Candidates. Basic Form.

This is a basic form which can be used for the evaluation of all component types, including electrical and non-electrical items.

Using this form Candidate Components are evaluated and compared in terms of their capabilities to meet the specified Requirements.

Figure 8. - Component Requirements vs. Candidates. Extended Form, Expanded Basic.

This form is similar in format and purpose to Figure 7. It differs only in that it allows more specific requirements entries under each of the general requirements.

Figure 9. - Component Requirements vs. Candidates. Extended Form. Detailed, General

This form is similar in purpose to Figure 7. It differs in that specific requirements are identified for each of the general requirements. This form was not intended for non-electrical items

Figure 10. - Component Requirements vs. Candidates. Extended Form. Detailed, Capacitors.

2.1.3

This form is used to compare and evaluate Candidate Capacitors in terms of their capabilities to meet specified Requirements. The form is intended to be used in the evaluation of capacitors for all applications and functions.

Figure 11. - Component Requirements vs. Candidates. Extended Form. Detailed, Diodes

This form is used to compare and evaluate Candidate Diodes (and Other Semi conductor Devices) in terms of their capabilities to meet specific Requirements. The form is intended to be used in the evaluation of Diodes and other semiconductor devices for all applications and functions.

Figure 12. - Component Requirements vs. Candidates. Extended Form. Detailed, Magnetics

This form is intended to be used in the evaluation of all Magnetics components including inductors and transformers for all applications. The form is used to compare and evaluate Candidate Magnetic Devices in terms of specific Requirements.

Figure 13. - Component Requirements vs. Candidates. Extended Form. Detailed, Resistors

This form is intended to be used in the evaluation of all Resistor products for all applications. The form is for use in comparing and evaluating Candidate Resistors in terms of specific Requirements.

Figure 14. - Component Requirements vs. Candidates. Open Form.

This form is similar in purpose to Figure 7, usable for both electrical and non-electrical components. Here the user identifies all of the Requirements and the Candidate Components to be evaluated.

Figure 15. Materials Requirements vs. Candidates. Basic Form.

This is a basic form for use in the evaluations of all materials, of any type - gas, liquid and solid, and for any application - electrical, mechanical, thermal and environmental. With this form Candidate Materials are compared and evaluated in terms of specific Requirements.

Figure 16. Materials Requirements vs. Candidates. Extended Form, Gases.

This form is intended for the evaluation of Candidate Materials which will exist and operate as Gases within the HVPS.

Figure 17. Materials Requirements vs. Candidates. Extended Form, Liquids.

This form is intended for the evaluation of Candidate Materials which will exist and operate as Liquids within the HVPS.

Figure 18. - Materials Requirements vs. Candidates. Extended Form, Solids.

This form is intended for the evaluation of Candidate Materials which will exist and operate as Solids within the HVPS.

Figure 19. - Materials Requirements vs. Candidates. Open Form.

This form is similar in purpose to Figure 15. Here the user determines all of the REQUIREMENTS and the Candidate Materials to be evaluated..

Figure 20. - Open Form, General Use.

This is a Requirements vs. Methods form which the user can employ for any appropriate evaluation. Here the user defines all of the Requirements and the General Method of Achievement, i.e. the Candidates to be evaluated.

2.1.5

2.2 Experimental Analyses and Development Forms

These forms are intended to assist in identifying areas of engineering and experimental analyses and in determining specific requirements associated with these analyses.

Figure 21. - Interaction Identification Form.

This form is intended to identify potential areas where further engineering and experimental analyses may be required. The form is to be used during the Requirements-Methods of Achievements evaluations. During these evaluations when areas of unknown or question behavior of an item and/or its environment are noted they should be recorded on the Interaction form. A summary of the types of entries for this form are given in Section 3.2.

Figure 22. - Interaction Identification Form.

This is a format variation of Figure 21. and would be used in the same manner.

Figure 23. - Model Test Structure (MTS) Variables.

This form is intended to identify the engineering and experimental details, in the form of the variables, which would be evaluated when and if topics identified in Figures 21 and 22 are selected for further analyses. The results derived from these forms would serve as the guidelines for any analyses or experimental evaluations associated with the topic under consideration.

2.3 Worksheets and Other Forms

Figure 24. - Worksheet

This form is intended to aid in the evaluations of candidate components and materials. This is accomplished by relating specific requirements (of an item) to the corresponding properties of the candidates. With an assigned value for the requirement, the corresponding property value of the candidate can be compared and the candidates adequacy determined.

Figure 25. - Commentary.

This form is to be used to record any comments determined necessary to provide comprehension to the other portions of the QFD Review.

3.0 Use of the QFD Forms.

3.1 The Requirements vs. Methods Forms.

The following section will describe the general use of the WHAT - HOW (or Requirements vs. Methods of Achievement) forms. The usage will be primarily demonstrated using the HVPS Requirements vs. Design form.

A sample of this form, shown in Figure 1A, has been numerically identified to aid in understanding its use. In the following sections each of the numerically identified areas will be explained.

HVPS REQUIREMENTS vs.
DESIGN
Basic form

Figure 1A. Area 1. HVPS Requirement vs. Design. Basic Form.

The title is generally based on the items or areas of Requirements and the Methods of Achievement. In this example the Requirements are HVPS Requirements and the Methods of Achievements are Candidate Designs, hence the form title.

Note that many of the Requirements vs Methods forms exist in several versions. The variations in forms dealing with the same topic are described in Section 2.1

PROGRAM ____________________

Item ________________________

Prepared by _________________

Date(s) _____________________

Figure 1A. Area 2.

This section identifies the Program or project associated with the QFD. Item here refers to the specific, system, subsystem, article, etc. under evaluation.

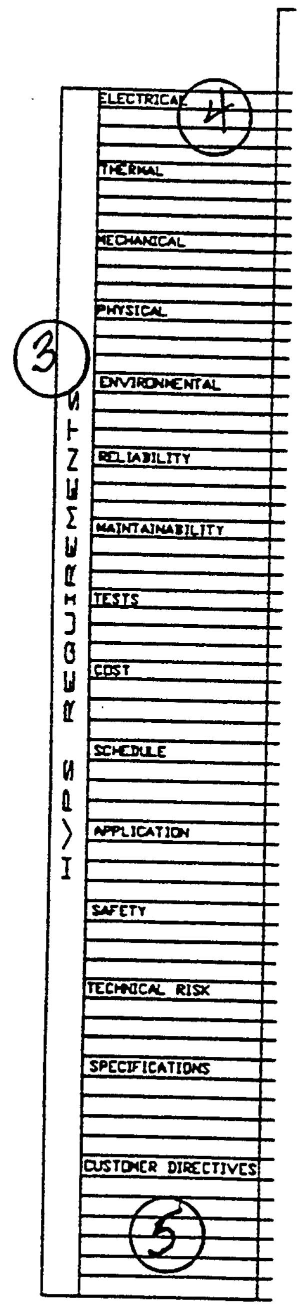


Figure 1A. Areas 3, 4 and 5.

2.1.9

Area 3 refers to the general topical area of Requirements under evaluation. In this example High Voltage Power Supply (HVPS) Requirements.

Area 4 identifies and lists subtopical areas whose Requirements must be met to achieve overall all acceptability of the general item under evaluation.

Note that in the Basic Forms general topical areas or items are identified such as in the Example form, Electrical, Thermal, Mechanical, etc.

For the most basic evaluation the major items or property requirements within these "general", Electrical,Thermal etc., areas would be lumped and the resulting assessment based on the lumped or combined determination.

At the next level of refinement key properties would be identified within each general area and the resulting assessment then based on the specific values and/or general determinations for each specific property. In the Basic Forms, spaces are available for 3-4 key properties. For example:

Electrical
- voltage, operate
- power
- efficiency

In the Extended versions of most forms, key properties are included. Those selected are ones most commonly encountered in High Voltage Power Supplies and their related requirements.

Two issues are of note for the Requirements sections of all forms. **First**, it's not necessary to define each general topic or listed property when performing evaluations. Use only those properties for which Requirements exist and/or those determined necessary to establish a satisfactory product.
Second, each form whether Basic or Extended has areas for both general topic additions and for additions of other key properties within topical areas. These areas of the forms are identified in Figure 1A. as Areas 4 and 5 respectively. Make additions in each area as appropriate to the evaluation being conducted.

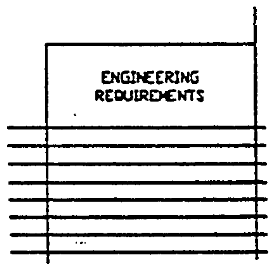


Figure 1A. Area 6.

This row is available for listing specific Engineering Requirements. These could include specific values for key properties, acceptance/rejection levels, less than/greater than values, merit factors, etc.

The use of this row is considered optional. When used, again, it is not necessary that each topic or key property have an entry.

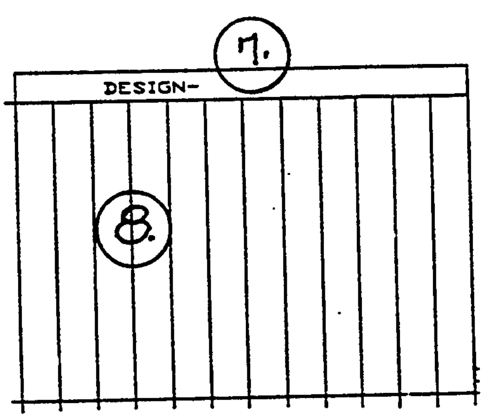


Figure 1A,. Areas 7 and 8.

This section of the form identifies the Methods of Achieving the requirements. Area 7. identifies the general area of achievement. In the example shown here it is high voltage power supply Designs. In the columns identified by Area 8. the specific candidates to be evaluated would be listed. Each of the Requirements vs. Methods of Achievement forms allows up to 12 candidates to be evaluated.

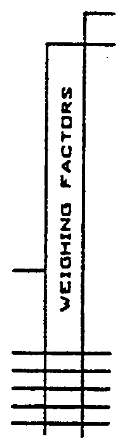


Figure 1A. Area 9.

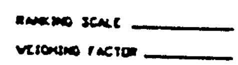


Figure 1A. Area 10.

The column identified by Area 9 provides for the use and notation of Weighing Factors which may be used in performing the evaluations. Weighing Factors or Weights define a numerical scale of relative importance for the specific requirements. Such scales are arbitrary. The principal consideration in selecting the scale range is that it be such as to permit a clear differential in properties when such differences are required or desired. For example a weighing factor scale of 0 to 5 where the difference are expresses in unit (1) increments will not be as differentiating as one of 0 to 10 also using unit (1) increments of difference.

An example of the use of Weighing Factors is shown in Figure 26. Here the weighing factor scale is 0 to 1.0 with minimum increment of 0.1. In this example the larger values represent relatively more important requirements. Area 10 identifies the Weight Factor Scale values when used in the evaluations. Area Item 10. also identifies a Ranking scale.

This value is intended to compare the specific properties of the Candidates (Methods of Achievement) in terms of a particular requirement. Here again a scale would be used and its values noted under Ranking.

In the example shown in Figure 26. the Ranking scale is 0 to 10 in unit (1) increments with the larger values indicating the candidate having the preferred properties for a given requirement.

For the example shown in Figure 26 when the Weighing Factor is (W.F.) is multiplied by the Rank Value (R..V.) the product is defined as the Assessed Value (A.V.),

$$A.V. = W.F. \times R.V.$$

This Assessed Value provides one of the means of Candidate (Methods of Achievement) evaluations. The candidate having the larger Assessed Value for a Requirement is considered superior.

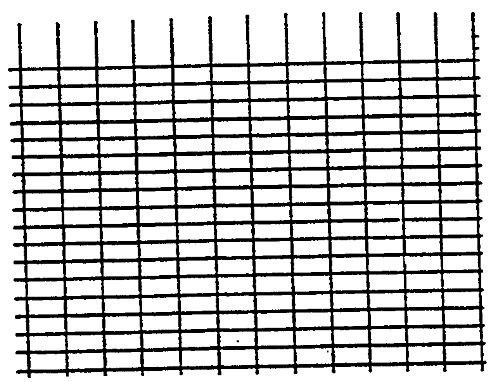


Figure 1A. Area 11

This is the Assessment portion of the form. In this area properties of the individual candidates are assessed in terms of the specific requirements they are intended to meet.

The use of this portion of the form is critical to the successful application of the QFD evaluation. It is in these Assessments that ultimately candidates are selected or discarded. It is also in these Assessments that candidates and variables are identified for the Interaction Studies. For

these reasons the Assessment phase of the QFD should be performed with appropriate rigor.

The following section present examples of methods which can be used in the Assessment process.

One method of assessment employs +, - and 0. In this method if a candidate property satisfies a requirement the assessment is given a +; if it fails to meet or satisfy the requirement the assessment is a -. Where the candidate property is neutral, not impacting or is the baseline a 0 is the assessment value. An example of the use of this method of assessment is shown in Figure 27.

It should be noted that when the +, -, 0 method is used, it may be weighted based on the relative importance of the requirements. For example a Weighting Factor Scale of 0 to 10 in unit (1) increments might be employed. If a Requirement has a Weighing Factor of eight (8) and a Candidate's property associated with that requirement is determined to meet that requirement, then that candidate be assigned 8+'s for that requirement. This method of evaluation is shown in Figure 28.

In another Assessment method Rank Values are used to compare the specific properties of the candidates to specific requirements. In the example shown in Figure 29 the Ranking Scale is 0 to 10 in unit (1) increments. A large Rank value means a particular candidate property more closely satisfies a requirement . A value of 10 means it completely meets that requirement.

In the last Assessment method discussed here Rank Values are combined with Weighing Factors to arrive at Assessed Values. In the example shown in Figure 26 and described previously the larger Assessed Values define a higher degree of both a particular requirement and overall product requirement satisfaction.

In using each of these or other Assessment methods, the goal should be to employ as much objectivity and factual inputs as can reasonably be done. This is to assure the maximum objectiveness in the final candidate selections.

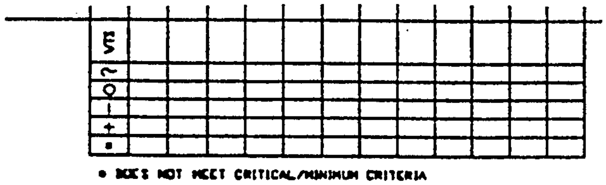


Figure 1A.. Area 12.

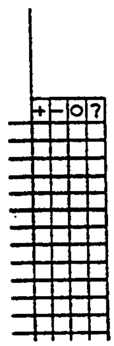


Figure 1A. Area 13.

These areas are the Evaluation sections in which the Assessment Summaries are presented. These summaries are described in two forms.

Item Area 12. presents the summary assessments for the candidates under review. In this summary either a numerical assessment is given, or a summarizing of the +'s, -'s and 0's is made. The candidate are then judged on the numerical comparisons or on the summaries of the +'s, -'s and 0's.

The Evaluation section described by Area 13. has been included to identify Requirements relationships to <u>ALL</u> candidates. Use of these Evaluators can identify both major and non problem areas common to all candidates. When either condition exists such information is useful in planning subsequent engineering evaluations following the QFD.

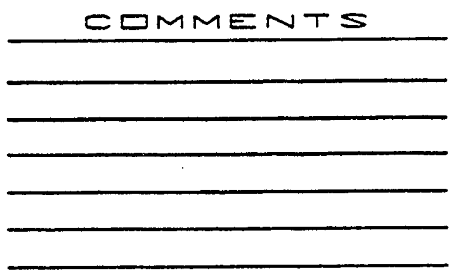


Figure 1A. Area 14.

Each of the Requirements - Methods of Achievement Forms contains a COMMENTS Column. This column is intended to contain any remarks, notes, considerations, etc. which are relevant to the evaluation.

As required the supplement Comments sheet, Figure 25,may be included as part of each evaluation form..

The procedures described previously have used the HVPS Requirement vs Design form to present the procedure for using the Requirements vs. Methods of Achievement form. This procedure would be the one followed for all forms of this type.

3.2 INTERACTION IDENTIFICATION FORM

Two versions of this form are available for use. Both serve the same function, and the selection of either is a matter of personal choice. The two forms are shown in Figures 21 and 22.

As the form title states these forms are intended to identify areas of possible Interactions whose resultant effects could alter the predicted performance of the component, material, subassembly, etc. from values derived from individual property evaluations.

The results derived from using these forms should aid in establishing the basic areas for subsequent engineering studies and evaluations in both -

- o arriving at final candidate selections
- o resolving and demonstrating design and selection details for the final HVPS configuration and construction.

As with all of the forms in this format the use of the Interaction Forms will and should be determined by individual needs and experience. The following are suggestions for their use.

As the Requirements vs. Methods of Achievement proceed - from the HVPS Requirements through Components and Materials evaluation, list the following types of items in the Interaction Identification form -

- o items where information regarding properties, performance, failure conditions, etc. is lacking either generally (all similar applications) or specifically (for the intended application).
- o items where information needs updating due to other factors such as process variations, new materials, design variations, different operating conditions, etc.
- o new applications of "old" technologies
- o new technologies
- o "blue sky" issues

The items to be included in the Interaction Form need not be highly detailed as the details for each item or area will be developed in the next phase of this evaluation, the Model Test Structures Variables Summary.

When the listing in the Interaction form is completed, one goes through the form and checks or fills in the row-column boxes where interactions are known or expected. An example of this identification process is shown in Figure 30. The identifications along with all of the items presented in the Interaction form provide the basis for the next step in the process, the use of the Model Test Structures Variables form.

3.3 MODEL TEST STRUCTURES (MTS)

Variable Summary

This form, shown in Figure 23, is intended to identify the variables to be evaluated using the Model Test Structure (MTS) approach. MTS's are physical test models which are so designed and constructed as to represent a set of conditions - design, components, materials, etc. - whose interactive behavior is to be evaluated. The focus in developing the MTS should be on the accuracy of the structure in terms of its replicating the conditions of interest, and on simplicity. The MTS should only reflect the variables and features of interest and need not be a complete HVPS or necessarily a complete subsystem.

The evaluation results from these MTS studies are intended to serve as the primary guide in

1- candidate evaluations and selections.
2- final HVPS configuration and construction.

The first step in the use of the MTS variables forms is the determination of which of the items listed in the Interaction Form are to be considered for further evaluations. This review should include a review of both the listed items and the listed items and their possible interactions.

Once the selections have been made the MTS Variables form comes into play.

First the item or topic of the MTS is identified. This is recorded in the section described by Figure 23A., Area 1.

MTS ______________________________

____

____

Figure 23A Area 1.

VARIABLES

Figure 23A. Area 2

Next, <u>all</u> of the identifiable variables associated with the MTS evaluations are listed. These should include both hardware issues and operating factors. This list is compiled in Area 2 of Figure 23A.

Having established the variables list, this list is then reviewed for the variables to be incorporated into the MTS for evaluation and analyses. This selection process maybe required in order to conduct a manageable experiment in which several variables are varied in order to assess their role in the behavior of the system under evaluation.

An alternate approach to the variable variations is to incorporate all of the significant variables into a single MTS and observe its performance. In either approach the variables to be evaluated should be identified and noted in Area 3 of Figure 23A.

TO BE EVALUATED

Figure 23A, Area 3.

Finally, Area 4 of Figure 23A is used for any COMMENTS associated with the use of this form.

COMMENTS

Figure 23A, Area 4.

An example of the use of the MTS Variables form is given in Figure 31.

The results of the review using this form are intended to guide the physical design of the Model Test Structures and to establish the conditions for its evaluation including the response parameters to be monitored.

3.4 WORKSHEET

This form, shown in Figure 24, is intended primarily as an aid in the evaluation of components and materials.

This is done by identifying particular Item/Product Requirements for the Candidate Component or Material being evaluated. These requirements are entered in the Item/Product Requirement column of the worksheet (see Figure 24A, Area 1.).

ITEMS/PRODUCT REQUIREMENT

Figure 24A, Area 1.

Next the CANDIDATE PROPERTY governing that requirement is identified and listed in Area 2 of Figure 24A.

CANDID. PROPERTY

Figure 24A, Area 2.

Then the Required value of this Property is entered in Area 3. of Figure 24A. This is typically a numerical value but may also be greater than/lesser than values, or PASS/FAIL CRITERIA.

PROPERTY REQUIREMENT

Figure 24A, Area 3.

Next the prospective CANDIDATES are listed in Area 4 of Figure 24A.

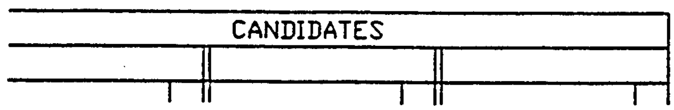


Figure 24A,Area 4.

The property values of the candidates corresponding to the CANDIDATE PROPERTY are then recorded in Area 5 of Figure 24A.

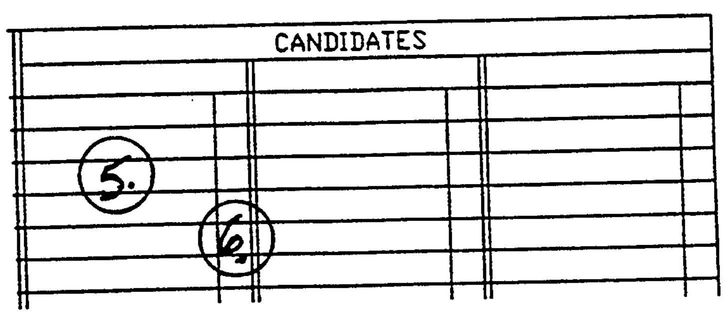


Figure 24A Areas 5 and 6.

Finally, the specific property of each CANDIDATE is judged in terms of its meeting the corresponding Property REQUIREMENT. Those properties of candidates meeting or exceeding the requirements are given a + in Area 6 of Figure 24A;.those not meeting the requirement are given a -; a marginal value is assigned an 0; and if no data is available a ? is recorded.

The last operation is to summarize and record the results in Area 7. of Figure 24A.

?	—					
O						
-						
+						
*						

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-6VS Rev. 9C

Figure 24A, Area 7.

Final candidate selections are supported by the results developed by this form. It may also be used in identifying areas where CANDIDATE PROPERTY characterization tests may be required before the selection process can be completed.

An example showing the use of the Worksheet is given in Figure 32.

3.5 COMMENTS

As noted by the title, this form, shown in Figure 25, is intended to be used for any and all commentary associated the evaluations of the QFD. Commentary is considered an important part of these evaluations in that it may provide bridges, rationales and insights into the various aspects of the evaluations.

The use of the COMMENTS sections of each of the forms along with the COMMENTS sheet is intended to assist in achieving a comprehensive and critical evaluation leading to a more effective selection of the choices to be made in developing the High Voltage Power Supply.

HVPS REQUIREMENTS vs. DESIGN
Basic form

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Date(s) ____________________

HVPS REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN-												+	−	O	?
ELECTRICAL																		
THERMAL																		
MECHANICAL																		
PHYSICAL																		
ENVIRONMENTAL																		
RELIABILITY																		
MAINTAINABILITY																		
TESTS																		
COST																		
SCHEDULE																		
APPLICATION																		
SAFETY																		
TECHNICAL RISK																		
SPECIFICATIONS																		
CUSTOMER DIRECTIVES																		

VTS											
?											
O											
−											
+											
*											

COMMENTS

RANKING SCALE __________

WEIGHING FACTOR __________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-1BA Rev. 92

Figure 1
2.1.24

1

HVPS REQUIREMENTS vs. DESIGN

Basic form

PROGRAM ______________

Item ______ 2 ______

Prepared by ______________

Date(s) ______________

6 ENGINEERING REQUIREMENTS

9 WEIGHING FACTORS

DESIGN– 7

8

11

+ | – | 0 | ?

13

14 COMMENTS

3 HVPS REQUIREMENTS

ELECTRICAL

4

THERMAL

MECHANICAL

PHYSICAL

ENVIRONMENTAL

RELIABILITY

MAINTAINABILITY

TESTS

COST

SCHEDULE

APPLICATION

SAFETY

TECHNICAL RISK

SPECIFICATIONS

CUSTOMER DIRECTIVES

5

VTS

?

0

–

+

*

12

RANKING SCALE ______

WEIGHING FACTOR __10__

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-IBA Rev. 92

Figure 1.A

PROGRAM ____________
Item ____________
Prepared by ____________
Date(s) ____________

HVPS REQUIREMENTS vs. DESIGN

Extended form, expanded basic

HVPS REQUIREMENTS	ENGINEERING REQUIREMENTS	VEIGHING FACTORS	DESIGN-	+	-	0	?
ELECTRICAL							
THERMAL							
MECHANICAL							
PHYSICAL							
ENVIRONMENTAL							
RELIABILITY							
MAINTAINABILITY							
TESTS							
COST							
SCHEDULE							
APPLICATION							
SAFETY							
TECHNICAL RISK							
SPECIFICATIONS							
CUSTOMER DIRECTIVES							
		VTS					
		?					
		0					
		-					
		+					
		*					

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

COMMENTS

RANKING SCALE ____________
VEIGHING FACTOR ____________

Form HHQ-1EX2 Rev. 92

Figure 2

2.1.26

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Date(s) ____________________

HVPS REQUIREMENTS vs. DESIGN

Extended form, detailed

HVPS REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN-											+	−	O	?	COMMENTS
ELECTRICAL																		
V OUT																		
V IN																		
POWER																		
EFFICIENCY																		
I IN																		
I OUT																		
MULTIPLE INPUTS																		
MULTIPLE OUTPUTS																		
FREQUENCY																		
PHASES																		
FAULT REQMTS																		
GROUNDING																		
THERMAL																		
TEMPERATURE RANGE																		
AMBIENT OPERATIONAL TEMP																		
RATE OF TEMP CHANGE																		
NUMBER TEMP CYCLES																		
COOLING METHOD																		
MECHANICAL																		
APPLICATION LOADS																		
SHOCK																		
VIBRATION																		
PHYSICAL																		
SIZE																		
DIMENSIONS																		
CONFIGURATION																		
WEIGHT																		
MOUNTING																		
ENVIRONMENTAL																		
MOISTURE RESISTANCE																		
SOLVENT/FUEL RESISTANCE																		
SALT SPRAY																		
RADIATION RESISTANCE																		
VACUUM EXPOSURE/OP																		
EMI/RFI																		
RELIABILITY																		
OP LIFE TIME																		
STORAGE REQMTS																		
FAILURE RATES																		
MAINTAINABILITY																		
SERVICE REQMTS																		
EASE OF REPAIR																		
SERVICE INTERVALS																		
TESTS																		
TYPES																		
QUALIFICATION																		
ACCEPTANCE																		
OPERATING																		
COST																		
ENGINEERING																		
PRODUCTION																		
SCHEDULE																		
ENGINEERING																		
PRODUCTION																		
APPLICATION																		
FUNCTION																		
SAFETY																		
PERSONNEL																		
USAGE/ENVIRON.																		
TECHNICAL RISK																		
NEW TECHNOLOGY																		
NEW APPLICATION																		
SPECIFICATIONS																		
MILITARY																		
COMPANY																		
CUSTOMER																		
CUSTOMER DIRECTIVES																		

VFS											
?											
O											
−											
+											
*											

RANKING SCALE __________

WEIGHING FACTOR __________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-1EXL Rev. 92

Figure 3

2.1.27

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Date(s) ____________________

HVPS REQUIREMENTS vs. DESIGN Open form

ENGINEERING REQUIREMENTS

WEIGHING FACTORS

DESIGN–

+ | – | O | ?

COMMENTS

RANKING SCALE ____________

WEIGHING FACTOR ____________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form MHO-7SJL Rev. 92

Figure 4
2.1.28

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Dates(s) ____________________

PACKAGING ELEMENTS vs. CANDIDATE DESIGNS

Basic form

PACKAGING ELEMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES/DESIGNS												+	−	O	?
STRUCTURE																		
ELECTRICAL INSULATION																		
THERMAL CONTROL																		
INPUTS																		
OUTPUTS																		
INTERCONNECTION																		
COMPONENTS																		
ASSEMBLY																		
TESTS																		
MAINTAINANCE																		
COST																		
TECHNICAL RISK																		
SPECIFICATIONS																		

VTS												
?												
O												
−												
+												
*												

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

COMMENTS

RANKING SCALE ____________

WEIGHING FACTOR ____________

Form HHQ-28A Rev. 92

Figure 5

2.1.29

PROGRAM ____________

Item ____________

Prepared by ____________

Dates(s) ____________

PACKAGING ELEMENTS vs. CANDIDATE DESIGNS

Open form

PACKAGING REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES/DESIGNS	+	–	O	?

VTS	
?	
O	
–	
+	
*	

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE ____________

WEIGHING FACTOR ____________

COMMENTS

Form HHQ-7SU2 Rev. 92

Figure 6

COMPONENT REQUIREMENTS vs. CANDIDATES
Basic form

PROGRAM__________
Item__________
Prepared by__________
Date(s)__________

COMPONENT REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	−	O	?	COMMENTS
ELECTRICAL																			
THERMAL																			
MECHANICAL																			
PHYSICAL																			
INTERCONNECTIONS																			
LEADS																			
ATTACHMENT																			
ENVIRONMENTAL																			
RELIABILITY																			
DERATING																			
MAINTAINABILITY																			
SAFETY																			
SPECIFICATIONS																			
COST																			
AVAILABILITY																			
TECHNICAL RISK																			
CUSTOMER DIRECTIVES																			

VTS												
?												
O												
−												
+												
*												

RANKING SCALE __________
WEIGHING FACTOR __________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form— HIQ-38A Rev. 92

Figure 7

2.1.31

COMPONENT REQUIREMENTS vs. CANDIDATES
Extended form, expanded basic

PROGRAM ____________________
ITEM ____________________
PREPARED BY ____________________
DATE(S) ____________________

COMPONENT REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	−	0	?
ELECTRICAL																		
THERMAL																		
MECHANICAL																		
PHYSICAL																		
INTERCONNECTIONS																		
LEADS																		
ATTACHMENT																		
ENVIRONMENTAL																		
RELIABILITY																		
DERATING																		
MAINTAINABILITY																		
SAFETY																		
SPECIFICATIONS																		
COST																		
AVAILABILITY																		
TECHNICAL RISK																		
CUSTOMER DIRECTIVES																		
		VTS																
		?																
		0																
		−																
		+																
		*																

COMMENTS

RANKING SCALE __________
WEIGHING FACTOR __________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form- HHO-3EX2 Rev. 92

Figure 8

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Date(s) ____________________

COMPONENT REQUIREMENTS vs. CANDIDATES

Extended form, detailed, general

COMPONENT REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	–	0	?	COMMENTS
ELECTRICAL																			
V RATED																			
V OPERATE																			
V BD																			
VCC (CORONA CHAR.)																			
POWER																			
EFFICIENCY (DISSIPATION)																			
TRANSIENTS																			
FREQUENCY																			
PHASES																			
FAULT REQMTS/TOLERANCE																			
THERMAL																			
T°OPERATE																			
T°MAX																			
T°MIN																			
STRESS EFFECTS																			
CONTROL REQUIREMENTS/METHODS																			
MECHANICAL																			
STRENGTH/ADEQUACY																			
ATTACHMENT																			
STRESSES																			
SHOCK																			
VIBRATION																			
THERMAL																			
PHYSICAL																			
SIZE																			
GEOMETRY																			
WEIGHT																			
INTERCONNECTIONS																			
INPUTS																			
OUTPUTS																			
NUMBERS																			
METHODS																			
LEADS																			
MATERIAL																			
FINISH																			
SOLDERABILITY																			
STRENGTH																			
ENVIRONMENTAL																			
HUMIDITY																			
SOLVENTS																			
ESD																			
RFI																			
RADIATION																			
RELIABILITY																			
MIL SPEC																			
OTHER																			
DERATING																			
ELECTRICAL																			
TEMPERATURE																			
MAINTAINABILITY																			
METHOD																			
FREQUENCY																			
SAFETY																			
PERSONNEL																			
USE/ENVIRON.																			
SPECIFICATIONS																			
CUSTOM																			
MILITARY																			
COMPANY																			
COST																			
AVAILABILITY																			
TECHNICAL RISK																			
NEW DEVICE																			
NEW APPLICATION																			
CUSTOMER DIRECTIVES																			

WTS												
?												
0												
–												
+												
*												

RANKING SCALE ____________

WEIGHING FACTOR ____________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Figure 9

Form HHQ-3EXL Rev. 92

COMPONENT REQUIREMENTS vs. CANDIDATES
Extended form, detailed, Capacitors

PROGRAM ______________________
Item ______________________
Prepared by ______________________
Date(s) ______________________

COMPONENT REQUIREMENTS – CAPACITORS

	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	-	0	?
ELECTRICAL																		
Vop																		
Vtest																		
CIV, CEV ac																		
CIV, CEV dc																		
C. TOL.																		
DF AT OP FREQ.																		
DF TEMP. RANGE																		
OP FREQ.																		
INSULATION RESIST.																		
STABILITY TEMP RANGE																		
STABILITY OP. LIFE																		
ESR																		
SRF																		
PRF																		
SURGE RESPONSE																		
ENERGY STORAGE																		
THERMAL																		
TEMP. MAX																		
TEMP. OP.																		
TEMP. RANGE																		
SHOCK-RANGE/CYCLES																		
CYCLE-RANGE/CYCLES																		
CTE																		
MECHANICAL																		
STRESS, MAJOR AXIS																		
STRESS, MINOR AXIS																		
ATTACHMENT METHOD																		
SUPPORTS																		
SHOCK – MAX.																		
VIBRATION – MAX.																		
PHYSICAL																		
SIZE – DIMEN.																		
SIZE – VOL.																		
CONFIG. LIMITS																		
WEIGHT																		
INTERCONNECTIONS/LEADS																		
NUMBERS																		
LOCATIONS																		
SIZE(S)																		
MATERIALS																		
PROCESS METHOD																		
ENVIRONMENTAL																		
MOISTURE RESIST.																		
SOLVENT RESIST.																		
PROCESS COMPAT.																		
ALTITUDE/PRESSURE																		
VACUUM																		
RELIABILITY																		
FAILURE RATE																		
FAILURE MODE																		
OP. LIFE																		
STORAGE LIFE																		
FAULT TOLERANCE																		
DERATING FACTORS																		
Vop																		
OP. TEMP																		
DESIGN FACTORS																		
ELECTRIC STRESS, MAX																		
ELECTRIC STRESS, OP.																		
ENERGY DENSITY, WT.																		
ENERGY DENSITY, VOL.																		
PACKAGING																		
ASSEMBLY COMPAT.																		
MAINTAINABILITY																		
REWORK COMPAT.																		
SPECIFICATIONS																		
CUSTOMERS																		
MIL. SPECS.																		
COMPANY																		
SAFETY/HEALTH																		
SPEC. HANDLING																		
SPEC. STORAGE																		
PERSONNEL																		
ENVIRONMENT																		
COST																		
DEVELOPMENT																		
UNIT PRICE																		
SPEC. TESTS																		
ATTRITION																		
STORAGE																		
AVAILABILITY																		
STD. PRODUCT																		
INTERCHANGEABLE																		
SOLE SOURCE																		
STABILITY MFR.																		
SCHEDULE																		
DEVELOPMENT																		
IMPLEMENT																		
PRODUCTION																		
TECHNICAL RISK																		
NEW DEVICE																		
NEW APPLICATION																		
NEW MFR.																		
CUSTOMER DIRECTIVES																		
REQUIRED TYPES																		
SUGGESTED TYPES																		
PROHIBITED TYPES																		
NONE																		

WTS												
?												
0												
-												
+												
*												

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE ______________________
WEIGHING FACTOR ______________________

COMMENTS

Form HHO-3EX3 Rev. 92

Figure 10

COMPONENT REQUIREMENTS vs. CANDIDATES

Extended form, detailed, Diodes

PROGRAM ____________

Item ____________

Prepared by ____________

Date(s) ____________

COMPONENTS REQUIREMENTS - DIODES

	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	-	0	?
ELECTRICAL							
Vrev. OP.							
Vrev. TEST							
Iop							
Itest							
P DISSIP. OP.							
P DISSIP. TEST							
Ppk. TURN-ON							
Ppk. TURN-OFF							
TURN-ON TIME							
TURN-OFF TIME							
OP FREQ.							
DUTY CYCLE							
Vmax TURN-OFF							
THERMAL							
TEMP. MAX							
TEMP. OP.							
TEMP. RANGE							
SHOCK-RANGE/CYCLES							
CYCLE-RANGE/CYCLES							
HEAT TRANSFER							
MECHANICAL							
STRESS, MAJOR AXIS							
STRESS, MINOR AXIS							
ATTACHMENT METHOD							
SUPPORTS							
SHOCK - MAX.							
VIBRATION - MAX.							
THERMAL STRESS							
PHYSICAL							
SIZE - DIMEN.							
SIZE - VOL.							
CONFIG. LIMITS							
WEIGHT							
INTERCONNECTIONS/LEADS							
NUMBERS							
LOCATIONS							
SIZE(S)							
MATERIALS							
PROCESS METHODS							
ENVIRONMENTAL							
MOISTURE RESIST.							
SOLVENT RESIST.							
PROCESS COMPAT.							
RADIATION RESIST.							
ALTITUDE/PRESSURE							
VACUUM							
RELIABILITY							
FAILURE RATES							
FAILURE MODE							
OP. LIFE							
STORAGE LIFE							
FAULT TOLERANCE							
FAULT PROTECTION							
DERATING FACTORS							
Vop							
P TURN-ON							
P TURN-OFF							
JUNCTION TEMP							
DESIGN FACTORS							
SINGLE JCN DEVICE							
MULTI JCN DEVICE							
PACKAGING							
CASE TYPE							
ASSEMBLY COMPAT.							
MAINTAINABILITY							
REWORK COMPAT.							
SPECIFICATIONS							
CUSTOMERS							
MIL SPECS.							
COMPANY							
COST							
DEVELOPMENT							
UNIT PRICE							
SPEC. TESTS							
ATTRITION							
STORAGE							
AVAILABILITY							
STD. PRODUCT							
INTERCHANGEABLE							
SOLE SOURCE							
STABILITY MFR.							
SCHEDULE							
DEVELOPMENT							
IMPLEMENT							
PRODUCTION							
TECHNICAL RISK							
NEW DEVICE							
NEW APPLICATION							
NEW MFR.							
CUSTOMER DIRECTIVES							
REQUIRED TYPES							
SUGGESTED TYPES							
PROHIBITED TYPES							
NONE							

COMMENTS

	CANDIDATES
V/S	
?	
0	
-	
+	
*	

RANKING SCALE ____________

WEIGHING FACTOR ____________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-3EX4 Rev. 92

Figure 11

COMPONENT REQUIREMENTS vs. CANDIDATES
Extended form, detailed, Resistors

PROGRAM ____________
Item ____________
Prepared by ____________
Date(s) ____________

COMPONENT REQUIREMENTS - RESISTORS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	−	0	?
ELECTRICAL							
V DEVICE							
V DEVICE - GND							
CIV, CEV ac DEVICE							
CIV, CEV ac DEVICE - GND							
CIV, CEV dc DEVICE							
CIV, CEV dc DEVICE - GND							
R, TOL.							
ΔR OP. TEMP RANGE							
ΔR AT Vop, Vtest							
STABILITY							
TRACKING							
NOISE							
INDUCTANCE @ OP. FREQ							
POWER DISSIP.							
THERMAL							
TEMP. MAX							
TEMP. OP.							
TEMP. RANGE							
SHOCK-RANGE/CYCLES							
CYCLE-RANGE/CYCLES							
HEAT TRANSFER							
MECHANICAL							
STRESS, MAJOR AXIS							
STRESS, MINOR AXIS							
ATTACHMENT METHOD							
SUPPORTS							
SHOCK - MAX.							
VIBRATION - MAX.							
THERMAL STRESS							
PHYSICAL							
SIZE - DIMEN.							
SIZE - VOL.							
CONFIG. LIMITS							
WEIGHT							
INTERCONNECTIONS/LEADS							
NUMBERS							
LOCATIONS							
SIZE(S)							
MATERIALS							
PROCESS METHODS							
ENVIRONMENTAL							
MOISTURE RESIST.							
SOLVENT RESIST.							
PROCESS COMPAT.							
RADIATION RESIST.							
ALTITUDE/PRESSURE							
VACUUM							
RELIABILITY							
FAILURE RATES							
FAILURE MODE							
OP. LIFE							
STORAGE LIFE							
FAULT TOLERANCE							
FAULT PROTECTION							
DERATING FACTORS							
P							
OP. TEMP.							
DESIGN FACTORS							
SINGLE DEVICE							
SERIES DEVICES							
PACKAGING							
CASE TYPE							
ASSEMBLY COMPAT.							
MAINTAINABILITY							
REVORK COMPAT.							
SPECIFICATIONS							
CUSTOMER							
MIL SPECS.							
COMPANY							
COST							
DEVELOPMENT							
UNIT PRICE							
SPEC. TESTS							
ATTRITION							
STORAGE							
AVAILABILITY							
STD. PRODUCT							
INTERCHANGEABLE							
SOLE SOURCE							
STABILITY MFR.							
SCHEDULE							
DELELOPMENT							
IMPLEMENT							
PRODUCTION							
TECHNICAL RISK							
NEW DEVICE							
NEW APPLICATION							
NEW MFR.							
CUSTOMER DIRECTIVES							
REQUIRED TYPES							
SUGGESTED TYPES							
PROHIBITED TYPES							
NONE							
		Σs					
		?					
		0					
		−					
		+					
		*					

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

COMMENTS

RANKING SCALE ____________
WEIGHING FACTOR ____________

Form HHO-3EX5 Rev. 92

Figure 12

COMPONENT REQUIREMENTS vs. CANDIDATES
Extended form, detailed,
Transformers

PROGRAM ______________
Item ______________
Prepared by ______________
Date(s) ______________

COMPONENT REQUIREMENTS - TRANSFORMERS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	−	O	?
ELECTRICAL							
VOLTAGE(S) OUT							
CURRENT(S) OUT							
VOLTAGE(S) IN							
CURRENT(S) IN							
WAVEFORM IN							
WAVEFORM(S) OUT							
RIPPLE							
NOISE							
FREQUENCY							
DUTY CYCLE							
REGULATION							
EFFICIENCY							
SWITCHING TRANSIENTS							
STORED ENERGY							
CIV/CEV							
DWV							
INSULATION RESIST. TEMP. RANGE							
SHIELDING							
BIL							
THERMAL							
TEMP. MAX - AMBIENT							
TEMP. OP. - AMBIENT							
TEMP. MAX - XFMR							
TEMP. RANGE							
SHOCK-RANGE/CYCLES							
CYCLE-RANGE/CYCLES							
MECHANICAL							
STRESSES, 3 AXES							
SUPPORTS							
ATTACHMENT METHOD							
SHOCK - MAX.							
VIBRATION - MAX.							
FATIGUE LEVEL							
THERMAL STRESS							
PHYSICAL							
SIZE - DIMEN.							
SIZE - VOL.							
CONFIG. LIMITS							
WEIGHT							
INTERCONNECTIONS/LEADS							
- INPUT							
NUMBERS							
LOCATIONS							
SIZE(S)							
MATERIALS							
PROCESS METHODS							
CONNECTORS							
- OUTPUT							
NUMBERS							
LOCATIONS							
SIZE(S)							
MATERIALS							
PROCESS METHODS							
CONNECTORS							
ENVIRONMENTAL							
MOISTURE RESIST.							
SOLVENT RESIST.							
PROCESS COMPAT.							
RADIATION RESIST.							
ALTITUDE/PRESSURE							
VACUUM							
EMI							
RFI							
RELIABILITY							
FAILURE RATES							
FAILURE MODE							
OP. LIFE							
STORAGE LIFE							
FAULT TOLERANCE							
FAULT PROTECTION							
DERATING FACTORS							
CORONA LEVELS							
TEMP. RANGE							
DESIGN FACTORS							
E MAX.							
E AVG.							
PACKAGING							
OPEN FORM							
ENCLOSED							
MAINTAINABILITY							
REWORK COMPAT.							
SPECIFICATIONS							
CUSTOMER							
MIL. SPECS.							
COMPANY							
COST							
DEVELOPMENT							
UNIT PRICE							
SPEC. TESTS							
ATTRITION							
STORAGE							
AVAILABILITY							
STD. PRODUCT							
INTERCHANGEABLE							
SOLE SOURCE							
STABILITY MFR.							
SCHEDULE							
DEVELOPMENT							
IMPLEMENT							
PRODUCTION							
TECHNICAL RISK							
NEW DEVICE							
NEW APPLICATION							
NEW MFR.							
CUSTOMER DIRECTIVES							
REQUIRED TYPES							
SUGGESTED TYPES							
PROHIBITED TYPES							
NONE							

COMMENTS

VTS	
?	
O	
−	
+	
*	

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE ______________
WEIGHING FACTOR ______________

Form HIQ-3CX6 Rev. 92

COMPONENT REQUIREMENTS vs. CANDIDATES
Open form

PROGRAM________________
ITEM________________
PREPARED BY________________
DATE(S)________________

COMPONENT REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	−	O	?	COMMENTS

*	+	−	O	?	VTS

RANKING SCALE ________
WEIGHING FACTOR ________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form- HHQ-7SU3 Rev. 92

Figure 14

PROGRAM ______________

Item ______________

Prepared by ______________

Date(s) ______________

MATERIALS REQUIREMENTS vs. CANDIDATES

Basic form

MATERIALS REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	−	0	?
ELECTRICAL																		
THERMAL																		
MECHANICAL																		
PHYSICAL																		
THERMO-DYNAMIC																		
ENVIRONMENTAL																		
PROCESSING																		
MAINTAINABILITY																		
RELIABILITY																		
SAFETY/HEALTH																		
SPECIFICATIONS																		
COST																		
AVAILABILITY																		
REPRODUCIBILITY																		
TECHNICAL RISK																		
USE LIMITS																		
CUSTOMER DIRECTIVES																		
		VTS																
		?																
		0																
		−																
		+																
		*																

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

COMMENTS

RANKING SCALE ______________

WEIGHING FACTOR ______________

Form MHO-43A Rev. 92

Figure 15

MATERIALS REQUIREMENTS vs. CANDIDATES
Extended form,
Gases

PROGRAM ____________
Item ____________
Prepared by ____________
Date(s) ____________

MATERIALS REQUIREMENTS - GAS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES												+	–	0	?
ELECTRICAL																		
Emax AT P OP.																		
Eavg AT P OP.																		
Emax TEMP. RANGE																		
Eavg TEMP. RANGE																		
Eavg																		
Emax TEST																		
Eavg TEST																		
CIV, CEV ac																		
CIV, CEV dc																		
Vop																		
Vtest																		
THERMAL																		
TEMP. RANGE QUAL.																		
TEMP. OP.																		
TEMP. RANGE OP.																		
TEMP. MAX																		
THERM. CONDUCTIVITY																		
SPECIFIC HEAT																		
FLOW RATE																		
PHYSICAL																		
DENSITY																		
BOIL PT.																		
MECHANICAL																		
P-MAX																		
CONTAINER																		
SEALING																		
ENVIRONMENTAL																		
MOISTURE TOLERANCE																		
SOLVENT TOLERANCE																		
RADIATION TOLERANCE																		
CHEMICAL COMPATIBILITY																		
CORONA EFFECTS																		
ARC EFFECTS																		
CONSTRUCTION MATLS.																		
COMPONENTS																		
RELIABILITY																		
CORONA EFFECTS																		
ARC RESIST																		
ARC EFFECTS																		
OP. LIFE																		
STORAGE LIFE																		
MAINTAINABILITY																		
ACCESSS																		
DISPOSAL																		
SEAL/CLOSE																		
REFILL																		
ENVIRON. REQNTS.																		
PROCESSING																		
DESIGN COMPAT.																		
SAFETY/HEALTH																		
TOXICITY																		
FLAMABILITY																		
CHEMICAL REACT.																		
SPECIFICATIONS																		
CUSTOMERS																		
MIL SPECS.																		
COMPANY																		
COST																		
DEVELOPMENT																		
IMPLEMENTATION																		
MANUFACTURING																		
MAINTENANCE																		
SCHEDULE																		
DELELOPMENT																		
IMPLEMENT																		
PRODUCTION																		
TECHNICAL RISK																		
NEW MATERIAL																		
NEW APPLICATION																		
BOTH																		
CUSTOMER DIRECTIVES																		
REQUIRED																		
RECOMMENDED																		
PROHIBITED																		
RESTRICTED USE																		
NONE																		
TESTS																		
MATERIALS CONTROLS																		
IN-PROCESS MONITORING																		
COMPLETED ASSY CHKG																		

VTS												
?												
0												
–												
+												
*												

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

COMMENTS

RANKING SCALE ____________
WEIGHING FACTOR ____________

Form MHO-4EX3 Rev. 92

2.1.40 Figure 16

PROGRAM ____________________

Item ____________________

Prepared by ____________________

Date(s) ____________________

MATERIALS REQUIREMENTS vs. CANDIDATES

Extended form,
Liquids

MATERIALS REQUIREMENTS - LIQUIDS

	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	−	0	?	COMMENTS
ELECTRICAL								
Emax OP.								
Emax TEST								
Eavg OP.								
Eavg TEST								
Emax TEMP. RANGE								
Eavg TEMP. RANGE								
CIV, CEV ac								
CIV, CEV dc								
Vmax OP.								
Vmax TEST								
DIELECTRIC CONST. @ OP. FREQ.								
DISSIPATION FACTORS @ OP. FREQ.								
DISSIPATION FACTORS @ TEMP. RANGE								
VOLUME RESIST TEMP. RANGE								
THERMAL								
TEMP. MAX								
TEMP. OP.								
TEMP. RANGE OP.								
TEMP. RANGE QUAL.								
THERM. CONDUCTIVITY								
SPECIFIC HEAT								
REYNOLDS NUMBER								
FLOW RATE								
THERMAL EXPAN. COEFF.								
PHYSICAL								
DENSITY								
VISCOSITY								
FREEZE PT.								
VAPOR PRESSURE								
MECHANICAL								
CONTAINER								
SEALING								
ENVIRONMENTAL								
MOISTURE TOLERANCE								
SOLVENT TOLERANCE								
CHEMICAL COMPATIBILITY								
CORONA EFFECTS								
ARC EFFECTS								
CONSTRUCTION MATLS.								
COMPONENTS								
RELIABILITY								
CORONA EFFECTS								
ARC RESIST								
ARC EFFECTS								
OP. LIFE								
STORAGE LIFE								
MAINTAINABILITY								
ACCESSS								
DISPOSAL								
REFILL								
SEAL/CLOSURE								
ENVIRON. REQMTS.								
PROCESSING								
DESIGN COMPAT.								
SAFETY/HEALTH								
TOXICITY								
FLAMABILITY								
CHEMICAL REACT.								
SPECIFICATIONS								
CUSTOMERS								
MIL SPECS.								
COMPANY								
COST								
DEVELOPMENT								
IMPLEMENTATION								
MANUFACTURING								
MAINTENANCE								
SCHEDULE								
DELELOPMENT								
IMPLEMENT								
PRODUCTION								
TECHNICAL RISK								
NEW MATERIAL								
NEW APPLICATION								
BOTH								
CUSTOMER DIRECTIVES								
REQUIRED								
RECOMMENDED								
PROHIBITED								
RESTRICTED USE								
NONE								
TESTS								
MATERIALS CONTROLS								
IN-PROCESS MONITORING								
COMPLETED ASSY CHKG								

	CANDIDATES
VIS	
?	
0	
−	
+	
*	

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE ____________

WEIGHING FACTOR ____________

Form HHQ-4EX2 Rev. 92

Figure 17

PROGRAM ____________
Item ____________
Prepared by ____________
Date(s) ____________

MATERIALS REQUIREMENTS vs. CANDIDATES
Extended form,
Solids

MATERIALS REQUIREMENTS - SOLIDS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	−	0	?
ELECTRICAL							
Vmax OP.							
Vmax TEST							
Emax OP.							
Emax TEST							
Eavg OP.							
Eavg TEST							
Emax TEMP. RANGE							
Eavg TEMP. RANGE							
DIELECTRIC CONST. @ OP. FREQ.							
DISSIPATION FACTORS @ OP. FREQ.							
DISSIPATION FACTORS @ TEMP. RANGE							
VOLUME RESIST TEMP. RANGE							
SURFACE RESIST TEMP. RANGE							
THERMAL							
TEMP. OP.							
TEMP. MAX							
TEMP. RANGE OP.							
TEMP. RANGE QUAL.							
SHOCK-RANGE/CYCLES							
CYCLE-RANGE/CYCLES							
THERM. CONDUCTIVITY							
SPECIFIC HEAT							
CTE							
MECHANICAL							
TENSILE STRENGTH							
FLEXURAL STRENGTH							
COMPRESS. STRENGTH							
SHOCK STRESS							
VIBRATION STRESS							
FATIGUE LIFE							
THERMAL STRESS							
PHYSICAL							
DENSITY							
HARDNESS							
ENVIRONMENTAL							
MOISTURE TOLERANCE							
SOLVENT TOLERANCE							
RADIATION TOLERANCE							
VAC. COMPAT.							
ESD COMPAT.							
EMI/RFI							
CHEMICAL COMPATIBILITY							
CONSTRUCTION MATLS.							
COMPONENTS							
RELIABILITY							
CORONA TOLERANCE							
ARC (SURF.) RESIST							
OP. LIFE							
STORAGE LIFE							
MAINTAINABILITY							
ACCESSS							
DISPOSAL							
REPLACE							
ENVIRON. REQMTS.							
PROCESSING							
DESIGN COMPAT.							
SAFETY/HEALTH							
TOXICITY							
FLAMABILITY							
CHEMICAL REACT.							
SPECIFICATIONS							
CUSTOMERS							
MIL SPECS.							
COMPANY							
COST							
DEVELOPMENT							
IMPLEMENTATION							
MANUFACTURING							
MAINTENANCE							
SCHEDULE							
DELELOPMENT							
IMPLEMENT							
PRODUCTION							
TECHNICAL RISK							
NEW MATERIAL							
NEW APPLICATION							
BOTH							
CUSTOMER DIRECTIVES							
REQUIRED							
RECOMMENDED							
PROHIBITED							
RESTRICTED USE							
NONE							
TESTS							
MATERIALS CONTROLS							
IN-PROCESS MONITORING							
COMPLETED ASSY CHKG							

COMMENTS

	CANDIDATES
VTS	
?	
0	
−	
+	
*	

RANKING SCALE ____________
WEIGHING FACTOR ____________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Figure 18

Form HHQ-4EXI Rev. 92

MATERIALS REQUIREMENTS vs. CANDIDATES
Open form

PROGRAM ____________
Item ____________
Prepared by ____________
Date(s) ____________

CANDIDATES

WEIGHING FACTORS

ENGINEERING REQUIREMENTS

MATERIALS REQUIREMENTS

+ − 0 ?

COMMENTS

* + − 0 ? V/S

RANKING SCALE ____________
WEIGHING FACTOR ____________

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-7SU4 Rev. 92

Figure 19

PROGRAM ____________

Item ____________

Prepared by ____________

Date(s) ____________

TITLE ____________

Open form, general use

ENGINEERING REQUIREMENTS	WEIGHING FACTORS	CANDIDATES	+	−	O	?

COMMENTS

\+ − O ? * V/S

RANKING SCALE ____________

WEIGHING FACTOR ____________

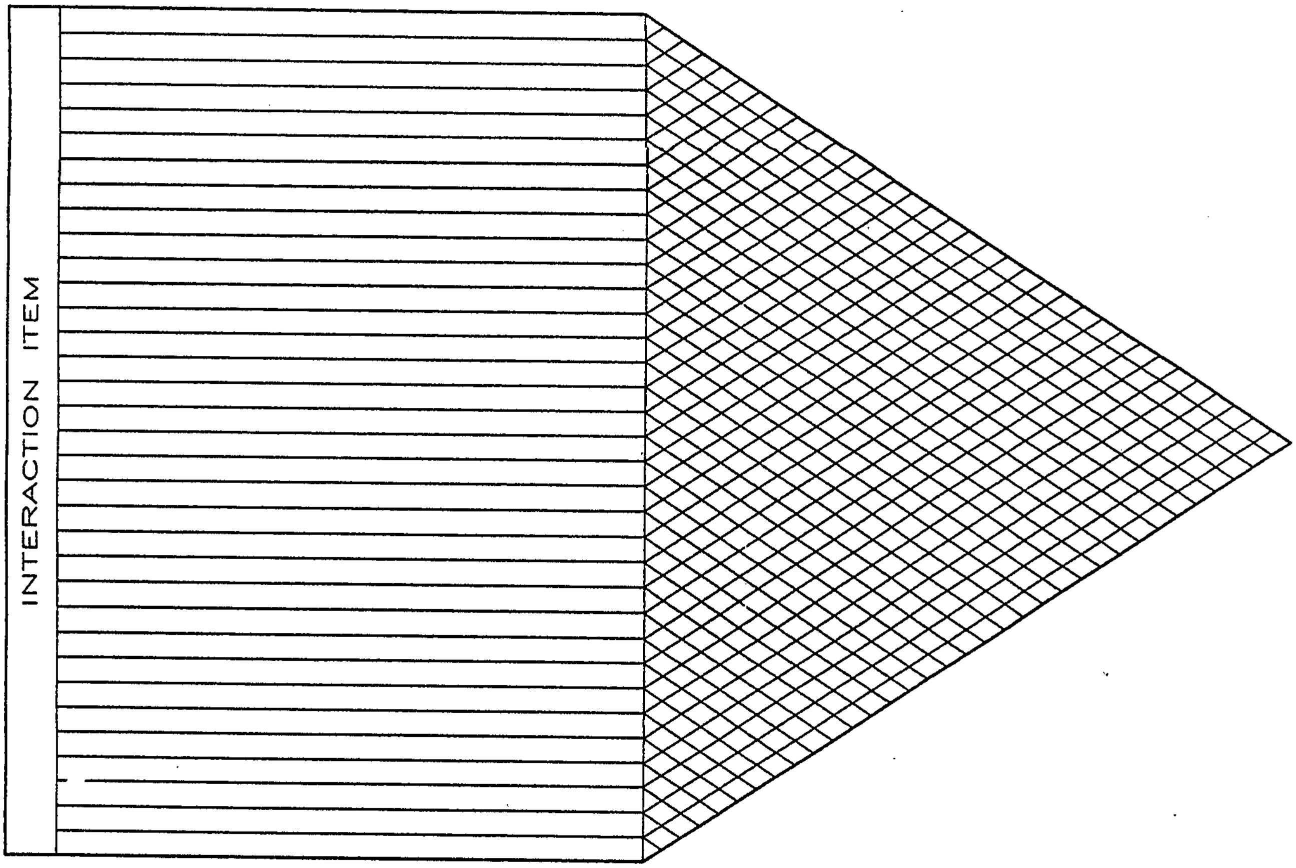
* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form HHQ-7SU5 Rev. 92

Figure 20

PROGRAM ____________________
Prepared by ____________________
Date(s) ____________________

INTERACTION IDENTIFICATION



COMMENTS

Figure 21

Form [illegible] Rev. 92

PROGRAM ________________
Prepared by ________________
Date(s) ________________

INTERACTION IDENTIFICATION

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																															
2																															
3																															
4																															
5																															
6																															
7																															
8																															
9																															
10																															
11																															
12																															
13																															
14																															
15																															
16																															
17																															
18																															
19																															
20																															
21																															
22																															
23																															
24																															
25																															
26																															
27																															
28																															
29																															
30																															

COMMENTS

Figure 22.

PROGRAM ____________________

Prepared by ____________________

Date(s) ____________________

Model Test Structure (MTS) Variables Summary

MTS ____________________

VARIABLES	TO BE EVALUATED	COMMENTS

Figure 23

PROGRAM ______________________

Prepared by ______________________

Date(s) ______________________

Model Test Structure (MTS)
Variables Summary

1. MTS	2. VARIABLES	3. TO BE EVALUATED	4. COMMENTS

Figure 23A.

PROGRAM ______________________

Item ______________________

Prepared by ______________________

Date(s) ______________________

WORKSHEET

ITEMS/PRODUCT REQUIREMENT	CANDID. PROPERTY	PROPERTY REQUIREMENT	CANDIDATES					
		?						
		O						
		-						
		+						
		*						

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

ITEMS/PRODUCT REQUIREMENT	CANDID. PROPERTY	PROPERTY REQUIREMENT	CANDIDATES					
		?						
		O						
		-						
		+						
		*						

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

[illegible]

Figure 24.

PROGRAM ______________________

COMMENTARY

Prepared by ______________________

Date(s) ______________________

COMMENTS

Figure 25.

PROGRAM MAN-TECH
Item EXAMPLE
Prepared by [illegible]
Date(s) 2-25-92

HVPS REQUIREMENTS vs. DESIGN
Basic form

HVPS REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN-APPROACH: GAS	DESIGN-APPROACH: SOLID	+	-	0	?	COMMENTS
ELECTRICAL		1.	6	8					
THERMAL		.8	4	6.4					
MECHANICAL		.8	4	6.4					
PHYSICAL		.7	4.2	4.4					
ENVIRONMENTAL		.7	3.6	3.5					
RELIABILITY		1.	4	6					
MAINTAINABILITY		.2	1.8	0.2					
TESTS		.4	3.2	3.2					
COST		.9	3.4	3.6					
SCHEDULE		.5	2.5	4.0					
APPLICATION		.6	4.8	4.8					
SAFETY		0	0	0					
TECHNICAL RISK		.3	2.1	1.2					
SPECIFICATIONS		.2	1.6	1.6					
CUSTOMER DIRECTIVES		0	0	0					
SUM			54.2	53.8					
?									
0									
-									
+									
*									

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE 0-10
WEIGHING FACTOR 0-1.0

Form HHD-13A Rev. 92

ASSIGNED VALUE = W.F. X RANK VALUE

PERFECT DESIGN = 81.

Figure 26.

PROGRAM MAN-TECH HYPS
ITEM [illegible]
PREPARED BY [illegible]
DATE(S) 17 [illegible]

REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN – SOLID	LIQ	GAS	GAS-SOLID
ELECTRICAL [illegible]			+	+	O	+
THERMAL [illegible]			+	+	O	+
MECHANICAL [illegible]			+	O	–	O
PHYSICAL [illegible]			O	O	–	O
ENVIRONMENTAL [illegible]			+	+	+	+
RELIABILITY [illegible]			O	+	+	+
MAINTAINABILITY [illegible]			–	O	+	+
TESTS [illegible]			O	O	–	O
COST [illegible]			–	O	–	+
SCHEDULE			+	O	–	O
APPLICATION [illegible]			+	+	–	O
SAFETY			O	O	O	O
TECHNICAL RISK [illegible]			+	+	–	O
SPECIFICATIONS [illegible]			+	O	–	O
CUST. DIR.			+	*	O	O
VIS						
?						
O			4	8	4	6
–			[illegible]	0	5	0
+			6	6	3	6
*				1		

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

RANKING SCALE ________

WEIGHING FACTOR ________

Form [illegible] Rev.

Figure 27.
2.1.52

HVPS REQUIREMENTS vs. DESIGN
Basic form

PROGRAM: MAN-TECH HVPS
Item:
Prepared by:
Date(s): 14 Apr 93

HVPS REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN: GAS	DESIGN: SOLID	COMMENTS
ELECTRICAL		10	10/0	10/+	
THERMAL		8	8/0	8/+	
MECHANICAL		8	8/-	8/+	
PHYSICAL		7	7/-	7/0	
ENVIRONMENTAL		7	7/+	7/+	
RELIABILITY		10	10/+	10/0	
MAINTAINABILITY		2	2/+	2/-	
TESTS		4	4/-	4/0	
COST		9	9/-	9/-	
SCHEDULE		5	5/-	5/+	
APPLICATION		6	6/-	6/+	
SAFETY		0			
TECHNICAL RISK		3	3/-	3/+	
SPECIFICATIONS		2	2/-	2/+	
CUSTOMER DIRECTIVES		0			
Σ					
?					
0					
-					
+					
*					

RANKING SCALE
WEIGHING FACTOR 0-10

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

	GAS	SOLID
0	18	11
-	45	11
+	19	49

Figure 28.
2.1.53

PROGRAM MAN-TECH HYPS
Item 6
Prepared
Date(s) 14 Apr 93

HVPS REQUIREMENTS vs. DESIGN
Basic form

REQUIREMENTS	ENGINEERING REQUIREMENTS	WEIGHING FACTORS	DESIGN: GAS	DESIGN: SOLID	+	-	O	?	COMMENTS
ELECTRICAL			6	8					
THERMAL			5	8					
MECHANICAL			5	8					
PHYSICAL									
ENVIRONMENTAL			8	5					
RELIABILITY			9	6					
MAINTAINABILITY			9	1					
TESTS			8	8					
COST			6	4					
SCHEDULE			5	8					
APPLICATION			8	8					
SAFETY									
TECHNICAL RISK			7	4					
SPECIFICATIONS			8	8					
CUSTOMER DIRECTIVES									
		Σ	84	76					
		?							
		O							
		-							
		+							
		*							

RANKING SCALE 0-10
WEIGHING FACTOR ______

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form [illegible]

Figure 29.

PROGRAM MAN-TECH HVPS

Prepared by GD

Date(s) 18 Apr 93

INTERACTION IDENTIFICATION

#	Item	1 PWB's HV	2	3 transform cord	4	5 HV ceramic caps	6	7 repairable encap	8	9 HV trans. insul	10	11 trans. insul. AC loss	12	13 HV diode-hi trans	14	15 HV conn-straight	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	PWB'S - HV	O				■		■						■																	
2																															
3	transformer cores			O						■		■																			
4																															
5	HV ceramic caps	■				O		■																							
6																															
7	repairable encap	■				■		O						■																	
8																															
9	HV trans. insul			■						O		■																			
10																															
11	trans. insul. ac loss			■						■		O																			
12																															
13	HV diodes-hi trans.	■						■						O																	
14																															
15	HV connectors-straight															O															
16																															
17																															
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30																															

COMMENTS

- multilayer ceramic chip cap's - not single layer

Form WHO-98A3 Rev. 92

Figure 30.

2.1.55

PROGRAM MAN-TECH, HVPS

Prepared by GH

Date(s) 18 Apr. 83

Model Test Structure (MTS)
Variables Summary

MTS HV PWB's

VARIABLES	TO BE EVALUATED	COMMENTS
substrate mat'l	constant	
" thk	"	
Cu - one side		
" - two sides	constant	
multilayer design		
conductor geometries	*	SQ. vs. curved corners
" spacing	*	
" thk		power points
" widths		heat transfer & power
" mat'l		
" surface finish		
substrate surf. treatment		
encapsulants	*	
thru-holes		
wires - type		insulated v. uninsulated
- sizes		
components - sizes		
" - mat'ls		
" - function		
Vop - surface to surf. conduct.	*	
" - thru substrate		
thermal stresses	*	temp. ranges, $\Delta T^{o}/\Delta t$'s
mechanical stresses		
environmental stresses		
RESPONSES		
CIV, CEV - ac & dc		
VBD dc		
life time @ Vdc & T°'s		

2.1.56 Figure 31.

PROGRAM MAN-TECH HVPS

Item HV module ENCAPSULANT

Prepared by [illegible]

Date(s) [illegible]

WORKSHEET

ITEMS/PRODUCT REQUIREMENT	CANDID. PROPERTY	PROPERTY REQUIREMENT	CANDIDATES					
			NO.1		NO.2		NO.3	
[illegible]	Thermal conductivity	0.6 BTU	0.5	−	0.65	+	0.5B	0
"								
Mech. [illegible]	[illegible]. Elastic mod.	800 ksi	750	−	780	0	850	+
[illegible]	T max. serv.	125°C	150	+	150	+	175	+
"	T min. serv.	−55°C	−65	+	−65	+	−65	+
	Tg	130°C	130	0	135	+	152	+
?								
0				1		1		1
−				2		0		0
+				2		4		4
*								

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

ITEMS/PRODUCT REQUIREMENT	CANDID. PROPERTY	PROPERTY REQUIREMENT	CANDIDATES					
?								
0								
−								
+								
*								

* DOES NOT MEET CRITICAL/MINIMUM CRITERIA

Form [illegible]

Figure 32.
2.1.57

Cen Base / Materials * Database Information

Appendix 2-2

Over 50,000 pages of Engineering Materials Property Data

on a single computer disc!

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Vol. 1, No. 4 **April 1991**

1,430 New Materials added to the 2Q91 disc! Over 170 megabytes or 50,000 pages of materials engineering data.

During last three months the editorial focus was to increase our coverage of the metals industry while at the same time keeping up with the changing plastics industry. We have begun a project to capture pertinent metals specification data from MIL-HDBK-5E. This is a military handbook produced and published by the Department of Defense in coordination with industry, Air Force, Navy, Army and the FAA on metallic materials for aerospace vehicle structures. The 2Q91 disc includes over 106 detailed records on standard grades of metals with physical property data, application text and cross-referenced ASTM, AMS, AA, FEDERAL, SAE, and MILITARY specifications. Future efforts will include the capturing of engineering plots for stress, fatigue, temperature plots, etc. Load search sequence named "0NEW.SEQ" or search the descriptions for "*".

New Materials added by the following manufacturer's

PLASTICS	
3M	38
Allied	2
Amoco Chemical	10
Aristech	81
BF Goodrich	24
BP Chemical	72
Colorite	7
Cyanamid	32
Cyro Industries	3
Dixon	4
Dow Chemical	10
Dupont	15
Eastman	22
Ferro	28
Fiberite	4
GE Plastics	7
Georgia Pacific	5
Hercules	1
Hoechst Celanese	32
Huntsman	8
M.A. Polymer	2
Monsanto	18
Novacor	11
Occidental	3
Paxon Polymer	6
Phillips	3
Polymerland	5
Rexene	22
Rototron	1
RTP Co	150
CERAMICS	
Ceralox	7
Certech	1
Coors	13
Eagle Picher	6
ERG	1
ESK	9
Hi Tech	1
Huls	15
Leco	4
TAM	18
Wisconsin	5
METALS	
Al Tech	10
Alcan	14
Alloy Metals	24
Alloy Tech	11
Ampco	1
Armco	8
Cabot	14
Cerro	9
Climax	30
CMP	6
Crucible	12
Fansteel	3
Gulf States	6
Harrison	47
Haynes	23
Hoskins	9
IRI	12
Kaiser	1
Lone Star	19
Metglas	8
Nuclear Metals	5
PMA	35
QIT	5
Reynolds	210
SCM	26
SPS	1
Teladyne	1
Uddelholm	1
SPECS (MIL-HDBK-5E)	106

Infotrieve™ Version 1.2

Our programming department has also been busy improving the retrieval software included on every CD-ROM disc. Version 1.2 includes a new two level interface to the massive property index. This new feature will allow users to find desired properties and perform min/max searches easier than in version 1.1. The two level interface first drops you into an outline index of all available properties. You search for a desired property and then press enter to expand that property (level 2) to select your desired min/max. In level 1, the system displays a frequency count that clues you in on what properties are being used the most, (very helpful for searching on commonly used properties). Property index is now sorted in ascending order versus descending. This also helps users interact with the massive property index.

Other new features include:
Wildcard Searching. The ability to wildcard a search request using the ? key. Example: DELRIN?,

NOT EQUAL searching. You can specify this request anytime after the first search pass.

Subscript out of range error. This problem has been fixed in version 1.2.

This newsletter is published every month by the editors of the CenBASE/Materials Database and Information Indexing, Inc.

Chris E. Nunez
President/Publisher

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ABS/PC	25
ABS/POLYOLEIN	1
ABS/PVC	24
ASA	10
ASA/PC	4
ACETAL	213
ACRYLIC	75
ACRYLIC/PVC	2
ACRYLIC SHEET	13
ACETATE	7
BUTYRATE	9
PROPIONATE	9
ETHYLENE ACRYLIC ACID	11
ETHYLENE ALPHA OLEFIN	7
ETHYLENE COPOLYMER	4
ETHYLENE n-BUTYL ACRYLATE	4
ETHYLENE VINYLACETATE (EVA)	81
ETHYLENE VINYL ALCOHOL	7
FLUOROCARBON AMORPHOUS	2
FLUOROCARBON CTFE	9
FLUOROCARBON ECTFE	5
FLUOROCARBON ETFE	13
FLUOROCARBON PTFE	62
FLUOROCARBON FEP	10
FLUOROCARBON PFA	9
FLUOROCARBON PVDF	39
FLUOROCARBON TFE	3
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LIQUID CRYSTAL POLYMER	41
LIQUID ENGINEERED	3
NYLON	102
NYLON 4/6	13
NYLON 6	562
NYLON 6/6	803
NYLON 6/9	5
NYLON 6/10	66
NYLON 6/12	132
NYLON 11	49
NYLON 12	109
POLYIMIDE	32
POLYARYLATE	10
POLYARYLETHERKETONE	13
POLYARYLAMIDE	6
POLYARYLSULFONE	12
POLYBUTYLENE	14
POLYCARBONATE	648
POLYCARBONATE/ABS	16
POLYCARBONATE/PET	11
POLYCARBONATE/PMMA	1
POLYCARBONATE/PBT	1
POLYESTER	37
POLYESTER/PCT	12
POLYESTER/PCTA	5
POLYESTER/PCTG	13
POLYESTER/LCP	8
POLYESTER/PBT ASA	6
POLYESTER/PBT PC	5
POLYESTER/PBT	340
POLYESTER/PET	146
POLYESTER/PETG	4
POLYESTER/TPPE	4
POLYETHERIMIDE	66
POLYETHERETHERKETONE (PEEK)	73
PEKEKK	8
POLYKETONE	12
POLYETHERSULFONE (PES)	92
POLYETHYLENE	1,396
POLYETHYLENE-CHLORINATED	20
POLYMETHACRYLIMIDE	11
POLYMETHYLMETHACRYLIC	2
POLYMETHYLMETHACRYLATE	12
POLYMETHYLPENTENE	27
POLYOLEFIN	29
POLYPHENYLENE ETHER	65
POLYPHENYLENE ETHER NYLON	9
POLYPHENYLENE ETHER/SB	18
POLYPHENYLENE OXIDE	107
POLYPHENYLENE SULFIDE	208
POLYPHENYLENE SULFIDE SULFONE	3
POLYPHENYLENYLSULFONE	2
POLYPHTHALAMIDE	8
POLYPROPYLENE	1,647
POLYSTYRENE	242
POLYSTYRENE/POLYPROPYLENE	4
POLYSULFONE	102
POLYVINYL CHLORIDE (PVC)	878
PVC/ASA	3
ADHESIVE POLYMER	49
BIODEGRADABLE	10
AMORPHOUS COPOLYMER	1
AMORPHOUS POLYMER	1
SAN	98
SMA	31
SOLUBLE PLASTIC	15
STYRENIC ALLOY	1
STYRENE BUTADIENE	8
STYRENIC COPOLYMER	3
ENGINEERED THERMOPLASTIC POLYMER	1
THERMOPLASTIC ALLOY	35
VINYL CHLORIDE/ACRYLATE	12
VINYLIDENE CHLORIDE	13
WEATHERABLE POLYMER	29
FLUOROELASTOMER	48
FLUOROSILICONE RUBBER	12
NITRILE ELASTOMER, Etc	131
POLYURETHANE	523
RUBBER	82
SILICONE	214
THERMOPLASTIC ELASTOMERS	551
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HARDENER	64
THERMOSET ACRYLIC	12
THERMOSET ALKYD	29
THERMOSET DAP	71
THERMOSET EPOXY	957
THERMOSET MELAMINE	5
THERMOSET MELAMINE PHENOLIC	12
THERMOSET PHENOLIC	452
THERMOSET POLYDICYCLOPENTADIENE	2
THERMOSET POLYESTER	545
THERMOSET POLYIMIDE	22
THERMOSET POLYURETHANE	64
THERMOSET SILICONE	19
THERMOSET VINYL ESTER	29
ALUMINUM	236
ALUMINUM BRONZE	25
BERYLLIUM COPPER	8
CASTING MATERIAL	39
BERYLLIUM TUBING	1
BISMUTH ALLOY	9
BRASS	16
BRONZE	12
CESIUM	1
CHROMIUM COBALT IRON	2
CHROMIUM IRON ALUMINUM	1
COBALT NICKEL CHROMIUM MOLY	1
COBALT NICKEL CHROMIUM TIN	2
COBALT ALLOY	15
COBALT NICKEL	1
COPPER	8
COPPER NICKEL ALLOY	1
COPPER NICKEL IRON	5
COPPER TIN	5
COPPER ALLOY	1
COPPER NICKEL	4
COPPER POWDER	5
DUCTILE IRON	5
GERMANIUM	1
HAFNIUM	1
IRON	1
IRON BASED ALLOY	5
IRON CHROMIUM ALUMINUM	3
IRON COBALT NICKEL	1
MANGANESE BRONZE	13
MOLYBDENUM	27
MUNTZ METAL	1
NICKEL	14
NICKEL ALLOY	40
NICKEL ALUMINUM MANGANESE	1
NICKEL BRAZING ALLOY	11
NICKEL CHROMIUM ALLOY	5
NICKEL CHROMIUM COPPER MOLY	1
NICKEL CHROMIUM	24
NICKEL CHROMIUM MOLYBDENUM ALLOY	1
NICKEL CHROMIUM COBALT ALLOY	6
NICKEL CHROMIUM IRON MOLY COPPER	2
NICKEL CHROMIUM IRON	16
NICKEL CHROMIUM MOLY COLUMBIUM	1
NICKEL COBALT ALLOY	2
NICKEL COPPER	1
NICKEL IRON	11
NICKEL IRON COBALT ALLOY	4
NICKEL IRON CHROMIUM MOLY COPPER	1
NICKEL MOLY	1
NICKEL SILVER	3
NIOBIUM	6
POTASSIUM	2
REINFORCED ALUMINUM	2
RUBIDIUM	1
SPECIALTY P/M POWDER	7
TANTALUM	9
TIN POWDER	4
TITANIUM	9
TUNGSTEN	4
URANIUM	4
VANADIUM	1
ZIRCONIUM	4
STAINLESS STEEL	118
STEEL	156
METALS SPECIFICATIONS (MIL-HDBK-5E)	97
COMPOSITES	526
ARAMID FIBER	3
CARBON FABRIC	6
CARBON FIBER	70
CONTINUOUS/CHOPPED FIBER	8
GRAPHITE FIBER	6
CERAMICS	479

TOTALS:

Thermoplastics	9,769
Elastomers	1,646
Thermosets	2,487
Composites & Fibers	623
Ceramics	468
Metals	1,094

TOTAL MATERIALS COUNT **16,101**

MAILINGS/MATL-CNT.CHP

Manufacturers listed in CenBASE™/Materials

3M Industrial Chemical Products Division
A. L. Hyde Company
A. Shulman Inc.
Acipco Steel Products
Accuratus Corp.
Airtech International, Inc.
Akzo Engineering Plastics
Al Tech Specialty Steel Corp.
Allied-Signal, Inc.
Amoco Chemical Company
Ampco Metal
Anderson Development Company
Applied Composites
ARCO Chemical
Aremco Products, Inc.
Aristech Chemical Corp.
Baltimore Specialty Steels Corp.,
Subsidiary of Armco, Inc.
Carbon Fibers Division, Ashland Oil, Inc.
Ashley Polymers, Inc.
Astralloy Wear Technology, Harsco Corp.
Astro Met Associates, Inc.
Atochem, Inc.
Ausimont, Inc.
Bacon Industries, Inc.
Bamberger Polymers, Inc.
BASF Corporation
Baycomp, A Div. of Bay Mill Ltd.
The Belland Corp.
Bethlehem Steel Corp.
B.F. Goodrich Specialty Division & Chemicals Division
Borden Chemical, A Div. of Borden, Inc.
Brush Wellman, Inc.
The Carbon/Graphite Group, Inc.
Cal Polymer, Inc.
Calcarb
The Carborundum Company
Castall, Inc.
Ceradyne, Inc.
Cercom, Inc.
Ceralox Corp.
Cerro Metal Products
Chevron Chemical Co.
Chomerics, Inc.
CIBA-GEIGY Corporation
Colorite
Comalloy International Corp.
Compounding Technology, Inc.
Conap, Inc.
Concept Polymer Technologies
Continental Polymers
Coors Ceramics Company
Dow Corning Corp.
Coshocton Stainless, Cyclops Corp.
Cosmic Plastics, Inc.
Custom Coating & Laminating Corp.
Custom Resins, A Div. of Bemis Co., Inc.
American Cyanamid Company
Cyro Industries
Deer Polymer Corporation
Degussa Corporation
Devcon Industrial Products Group
Dexter Plastics, The Dexter Corp.
Diamonite Products
Dixon Industries Corporation
The Dow Chemical Group
DSM-RIM Nylon, Inc.
Du Pont Canada, Inc.
Du Pont USA (E.I. Du Pont De Nemours & Co., Inc.)
Duramic Products, Inc.
Dylon Ceramic Technologies
Eagle Picher Industries
Eastman Kodak Co., Performance Plastics, Eastman Chemicals Division
EDO Corporation
EGC Corporation
Emerson & Cuming
Emser Industries
Epic Resins
Epoxy Technology, Inc.
The Epoxylite Corporation
ERTA Incorporated
ESK Engineered Ceramics
Ethyl Corporation
EniChem Elastomeri SpA
Eval Company of America
Exxon Chemical Company
Ferro Corporation
Fiberite Molding Materials, An ICI Company
Filmco Industries
Fina Oil and Chemical Company
Fireline, Inc.
Firestone Synthetic Rubber & Latex Co.
Furon
Fiber Materials, Inc.
Fortafil Fibers, Inc., Great Lakes Carbon Corporation
Freeman Chemical Corporation
Formulated Systems Group, CIBA-GEIGY Corporation
GBC Materials Corp.
General Electric Company
Gencorp Company, Plastic Film Division
Genesis Polymers
Georgia Gulf Corporation
Glastic Company
Granmont, Inc.
Green, Tweed Engineered Plastics
Griffith Polymers, Inc.
Gulf States Steel Company
Haysite Reinforced Plastics
Hercules Aerospace Co.
Hexcel Corporation
Hi-Tek Polymers, Inc.
Hi-Tech Ceramics, Inc.
Himont U.S.A., Inc.
Hoeschst Celanese Corporation
Howmet Corp.
HULS America Inc.
Hunstman, Chemical Corporation
Hysol Electronic, Chemicals Division
Industrial Dielectrics, Inc.
ICI Films
Inco Alloys International, Inc.
International Polymer Corporation
Ipsen Ceramics
J-VON, A Division of Jones & Vining, Inc.
Jessop Steel Co.
K-BIN, Inc.
Kaneka America Corporation
Keramont Corporation
Keysor-Century Corporation
Kyocera America, Inc.
Lambertville Ceramic
La Salle Steel Co.
Latrobe Steel Co.
Leco Corp.
LNP Engineering Plastics, ICI Advanced Materials
Lourich Company
LSP Industrial Ceramics, Inc.
M.A. Industries, Inc.
McCann Manufacturing, Inc.
Mearthane Products Corporation
Hercules Aerospace Co.
Mitsui & Co. USA, Inc.
Mobay Corporation
Mobil Chemical Company
Modified Plastics
Monmouth Plastics, Inc.
Monsanto Chemical Company
Montedison USA, Inc.
Morton Thiokol, Inc.
MPD, Inc.
MRC Polymers, Inc.
Mykroy/Mycaley Ceramics
National Starch and Chemical Corp.
Newport Composites, Inc.
NIDI
Norplex/Oak
Norton Corp., Norton Performance Plastics Norton Industrial Ceramics
Novacor Chemicals, Inc.
Occidental Chemical Corporation
Oremet Titanium
Phillips 66 Company
Plaskolite, Inc.
Plaskon Electronic Materials, Inc.
Plastics Engineering Company
Polifil, Inc.
Polycast Technology Corporation
Polyfil, Inc., Royalite Thermoplastics Div.
Polymer Composites, Inc.
The Polymer Corporation
Polymer Technologies
Polyply, Inc.
Polysar Incorporated
Premix, Inc.
Quantum Composites, Inc.
Raymark Friction Co.
Reichhold Chemicals, Inc.
Renosol Corporation
Resinoid Engineering Corporation
Rexene Resins
Rhone-Poulenc Inc.
Rodgers Engineering Corporation
Rogers Corporation
Rohm and Haas Corporation
Rohm Tech, Inc., A Subsidiary of Rohm GmbH
Rostone
Rototron Corp.
Royalite Thermoplastics Division, Polycast Technology Corp.
RTP Company
SABIC Marketing Ltd.
Sheffield Plastics, Inc.
Shell Chemical Company
Sherex Chemical Company
Shuman Plastics
Signode Packaging Systems Division
Silmar (A Division of Standard Oil Engineered Materials)
SOLTEX Polymer Corporation
SOLVAY & Cie
Stackpole Fibers Co.
Steward Ferrites
TACC International Corporation, Formulated Resins Division
Taita Chemical Co., Ltd.
Tam Ceramics, Inc.
Teledyne Wah Chang Albany
Tenneco Polymers, Inc.
Tetraflour, Inc.
Texapol Corp.
Textron
Thermofil, Inc.
Thermal Ceramics
Thermoset Plastics, Inc.
Toray Industries (America), Inc.
Tuftane, Film Products Division
USI Division, Quantum Chemical Corp.
UBE Industries, Ltd.
Union Carbide
Valite
Visilox Systems, Inc.
Vista Polymers, Inc.
Washington Penn Plastic Co., Inc.
Wellman, Inc.
Wesgo Division, GTE Products
Wisconsin Porcelain
Zeon Chemicals, Inc.
Zircar Products, Inc.
Zircoa, Inc.

As of December 1990

```
/PHYSICAL PROPERTIES
/LAST_REVISED: 06/06/91      EFFECTIVE DATE:
/=========================================
/MATERIAL CATEGORY   : THERMOPLASTIC
 MATERIAL TYPE       : POLYAMIDE-IMIDE
/MATERIAL MFG        : AMOCO
/MATERIAL TRADE NAME: TORLON 2000
/FILLER TYPE         :
/FORM                :
/
/Mechanical Properties @Room Temp                              Value
/-----------------------------------------------------------------------
Elongation.@Yld...............(ASTM.D638).%(MD):.............15.00
Flexural.Modulus..............(ASTM.D790).100ksi[GPa]:.......6.15[4.24]
Flexural.Str..................(ASTM.D790).ksi[MPa]:..........24.00[165.36]
Impact.Str.Notched.Izod.1/8" .(ASTM.D256).ft-lbs/in[J/m]:....3.50[186.90]
Tensile.Str.@Yld..............(ASTM.D638).ksi[MPa](MD):......19.00[13.09]
/
/Physical Properties @Room Temp                                Value
/-----------------------------------------------------------------------
Cost/lb..............(40000.lbs).$/lb:.......................21.75
/(Note): 22,000 lb and over
Cost/cuin............=(SG)x(0.0361)x(cost/lb).$/cuin:........1.0757
Specific.Gravity(SG).....(ASTM.D792):........................1.37
/
/Processing Properties @Room Temp        (Injection Molding) Value
/-----------------------------------------------------------------------
Back.Pressure........................psi:....................30-100
Barrel.Temp.Front....................F[C]:...................640-660[338-349]
Barrel.Temp.Mid......................F[C]:...................630-650[332-343]
Barrel.Temp.Rear.....................F[C]:...................610-630[321-332]
Injection.Pressure...................MPa:....................Minimum
Injection.Pressure...................psi:....................Minimum
Material.Drying.Temp.................F[C]:...................275[135]
Melt.Temp............................F[C]:...................670[354]
Mold.Shrinkage(1/8").....(ASTM.D955).in/in:..................0.008
Mold.Temp............................F[C]:...................320-410[160-210]
Nozzle.Temp..........................F[C]:...................645-670[341-354]
Recommended.Drying.Time..............hrs:....................2
Screw.Speed..........................rpm:....................Moderate-Fast
/
/Thermal Properties @Room Temp                                 Value
/-----------------------------------------------------------------------
Deflection.Temp....(ASTM.D648).@264psi.F[C]:.................515[268]
<END>
```

```
/PHYSICAL PROPERTIES
/LAST_REVISED: 04/05/91     EFFECTIVE DATE:
/=========================================
/MATERIAL CATEGORY  : METAL SPEC
 MATERIAL TYPE      : STEEL
/MATERIAL TRADE NAME: 4340
/MATERIAL SOURCE    : MIL-HDBK-5E
/FORM               : WROUGHT, BARS, FORGING, TUBING
/
/Mechanical Properties - Wrought, Air Melted                   Value
/--------------------------------------------------------------------
Tensile.Str.............................ksi[MPa]:..............260.00[1791]
Tensile.Str.@0.2%.Offset................ksi[MPa]:..............215.00[148.14]
Compressive.Str.@0.2%.Offset............ksi[MPa]:..............240.00[165.36]
Shear.Str...............................ksi[MPa]:..............156.00[107.48]
Bearing.Str.@Yld........................ksi[MPa]:..............347.00[239.08]
Bearing.Str.@0.2%.Offset................ksi[MPa]:..............309.00[212.90]
Elastic.Modulus.........................100ksi[GPa]:.......290.00[199.81]
Rigidity.Modulus........................10^6.psi:..............11.00
Poisson's.Ratio:........................................0.32
/
/Physical Properties @Room Temp                                Value
/--------------------------------------------------------------------
Density...........................lbs./in^3[gm/cm^3]:..........0.283[7.83]
/
/Thermal Properties @Room Temp                                 Value
/--------------------------------------------------------------------
Coef.Linear.Exp...............10^-5in/in/F[10^-5m/m/C]:..........0.6[1.05]
Conductivity..................Btu-in/hr/ft^2/F[W/m-K]:...........10-22[1.4-3.2]
Specific.Heat.................Btu/lbs./F[J/Kg/K]:................0.5-0.9[1-2]
/
Chemical Composition Properties -Typical                       Value
/--------------------------------------------------------------------
Carbon.(C)......................%:...........................0.38-0.43
Chromium.(Cr)...................%:...........................0.70-0.90
Manganese.(Mn)..................%:...........................0.60-0.80
Molybdenum.(Mo).................%:...........................0.20-0.30
Nickel.(Ni).....................%:...........................1.65-2.00
Phosphorus.(P)..................%:...........................0.035
/(Note):
Silicon.(Si)....................%:...........................0.15-0.30
Sulfur.(S)......................%:...........................0.040
/(Note):
/
<END>
```

/APPLICATIONS DATA
/LAST_REVISED: 07/09/90 EFFECTIVE DATE:
/==
/MATERIAL CATEGORY : THERMOPLASTIC
MATERIAL TYPE : POLYAMIDE-IMIDE
,MATERIAL MFG : AMOCO
/MATERIAL TRADE NAME: TORLON 7330
/FILLER TYPE :
/FORM :
/
/======Description===

TORLON Polyamide-imides are in a class by themselves among the engineering resins. They stand up under conditions often considered too severe for thermoplastics. While some resins may take 500 degrees (F) conditions for intermittent service. TORLON polymers maintain their strength at this elevated temperature. Polyamide-imides have, for this reason, been chosen for parts in the space shuttle and for experimental race car engine components.

Performance properties include strength retention over a wide range of temperatures and sustained stress, low creep, flame resistance, outstanding electricals, and high integrity in sever environments.

The high modulus of TORLON resins make them a good replacement for metal where stiffness is crucial to performance. TORLON parts can provide equivalent stiffness at significantly lower weights. Fatigue strength, impact resistance, fracture toughness and retention of properties after thermal aging are all in the exceptional category.

These high performance, molding grade resins are virtually unaffected by aliphatic and aromatic hydrocarbons, chlorinated and fluorinated hydrocarbons and by most acids at moderate temperatures. Of particular interest to .rospace and automotive engineers is the ability of TORLON polymers to hold their properties after exposure to lubricating fluids, turbine oils and hydraulic fluids.

TORLON 2000 Series resins have been developed to complement the standard TORLON product line with resins that offer easier processibility on standard injection molding machines and shorter cure times. The new grades demonstrate improved flow which allows the ability to mold larger parts, longer sections with more cavities per mold. This provides more versatility in the size and complexity of parts that could not be molded in the standard TORLON grades. The shorter cure cycles give the molder more flexibility in meeting production schedules for parts.

While the TORLON 2000 series resins offer significantly improved procesing parameters, the broad mechanical properties are retained.

Typical applications for TORLON 2000 series are in the areas of chemical processing, automotive, aviation/aerospace, machinery/bearings, electrical/electonic industries and in wear-resistant applications like components for industrial compressors.
<END>

CHEMICAL RESISTANCE OF TORLON 4203 LAST REV.DATE: MAR 6,1990

After 24 hour exposure at 93°C (200°F) unless otherwise noted.

Chemical Agents	% Retained (Tensile Strength)
Acids:	
Acetic (10%)	100
Glacial Acetic	100
Acetic Anhydride	100
Lactic	100
Benzene Sulfonic	28
Chromic (10%)	100
Formic (88%)	66
Hydrochloric (10%)	100
Hydrochloric (37%)	95
Phosphoric (35%)	100
Sulfuric (30%)	100
Bases:	
Ammonium Hydroxide (28%)	81
Sodium Hydroxide (15%)	43
Sodium Hydroxide (30%)	7
Aqueous Solutions	
(10% unless otherwise noted)	
Aluminum Sulfate	100
Ammonium Chloride	100
Ammonium Nitrate	98
Ammonium Sulfate	100
Barium Chloride	100
Bromine (Saturated solution, 120°F)	100
Calcium Chloride	100
Calcium Nitrate	96
Ferric Chloride	99
Magnesium Chloride	100
Potassium Permanganate	100
Sodium Bicarbonate	100
Silver Chloride	100
Sodium Carbonate	100
Sodium Chloride	100
Sodium Chromate	100
Sodium Hypochlorite	100
Sodium Sulfate	100
Sodium Sulfide	84
Sodium Sulfite	100
Water	100
Alcohols	
2 Aminoethanol	9
Amyl Ethanol	100
Butyl Ethanol	100
Cyclohexanol	100
Ethylene Glycol	100
Amines	
Aniline	97
n Butylamine	100
imethylaniline	100
Ethylenediamine	7
Morpholine	100

Pyridine	43
Aldehydes & Ketones	
Acetophenone	100
Benzaldehyde	100
Cyclohexanone	100
Formaldehyde (37%)	100
Furfural	84
Methyl Ethyl Ketone	100
Chlorinated Organics	
Acetyl Chloride (120°F)	100
Benzyl Chloride (120°F)	100
Carbon Tetrachloride	100
Chlorobenzene	100
2 Chloroethanol	100
Chloroform (120°F)	100
Epichlorohydrin	100
Ethylene Chloride	100
Esters	
Amyl acetate	100
Butyl acetate	100
Butyl phthalate	100
Ethyl acetate	100
Butyl Ether	100
Cellosolve	100
p Dioxane (120°F)	100
Tetrahydrofuran	100
Hydrocarbons	
Cyclohexane	100
Diesel fuel	99
Gasoline (120°F)	100
Heptane	100
Mineral Oil	100
Motor Oil	100
Stoddard Solvent	100
Toluene	100
Xylene	100
Nitriles	
Acetonitrile	100
Benzonitrile	100
Nitro Compounds	
Nitrobenzene	100
Nitromethane	100
Miscellaneous	
Cresyldiphenyl Phosphate	100
Sulfolane	100
Triphenylphosphite	100

+++
<END>

```
/ADVANCED ENGINEERING DATA
/GE Engineering Design Database
/LAST_REVISED: 6/26/91
/========================================================================
 MATERIAL CATEGORY   : THERMOPLASTIC
/MATERIAL TYPE       : POLYCARBONATE
/MATERIAL MFG        : GENERAL ELECTRIC
/MATERIAL TRADE NAME: LEXAN 101
/FILLER TYPE         :
/========================================================================

MOLDFLOW CONSTANTS
------------------
Specific.heat.of.melt............(J/KG-DEG(C)): 2052.00
Thermal.Conductivity...........(J/M-SEC-DEG(C): 0.320
Melt.Density.........................(KG/M**3): 1017.000
Freeze.Temperature....................(DEG(C)): 152.000
No-Flow.Temperature...................(DEG(C)): 175.000
Vicosity.Constant.A...........................: -553765
Shear.Constant.B..............................: -0.270
Temperature.Constant.C........................: -0.018
2nd.order.fit.constant.A1.....................: 0.87713E+01
2nd.order.fit.constant.A2.....................: -031218E+00
2nd.order.fit.constant.A3.....................: 0.10383E-01
2nd.order.fit.constant.A4.....................: -0.86242E-01
2nd.order.fit.constant.A5.....................: 0.36695E-02
2nd.order.fit.constant.A6.....................: -0.80226E-04

RHEOLOGY DATA
-------------

 /#1 |===============|    Shear Rate vs. Viscosity     |==================
Apparent Shear Rates and Viscosity at specific temperatures.
========================================================================
%BeginGraph
Title.: SHEAR RATE as a function of VISCOSITY
Sub...: (LEXAN 101)
Xtitle: Shear Rate (Sec -1)
Ytitle: Viscosity (Pa * sec)
Nplots: 3
-------------------------------------------------------------------
T: 320 deg C
X: 10000 ,6310 ,3980 ,2510 ,1580  ,1000 ,631  ,398  ,251  ,158  ,100 /
Y: 90    ,119  ,162  ,209  ,268   ,313  ,354  ,382  ,399  ,410  ,415 /
-------------------------------------------------------------------
T: 330 deg C
X: 10000 ,6310 ,3980 ,2510 ,1580  ,1000 ,631  ,398  ,251  ,158  ,100 /
Y: 84    ,111  ,143  ,187  ,231   ,267  ,292  ,308  ,319  ,321  ,324 /
-------------------------------------------------------------------
T: 340 deg C
X: 10000 ,6310 ,3980 ,2510 ,1580  ,1000 ,631  ,398  ,251  ,158  ,100 /
Y: 78    ,100  ,126  ,157  ,191   ,217  ,234  ,247  ,251  ,259  ,263 /
-------------------------------------------------------------------
%EndGraph

MOLDFLOW is a registered trademark of MOLDFLOW Ltd.
<END>
```